Flood Frequency and Mixed Populations in the Western United States

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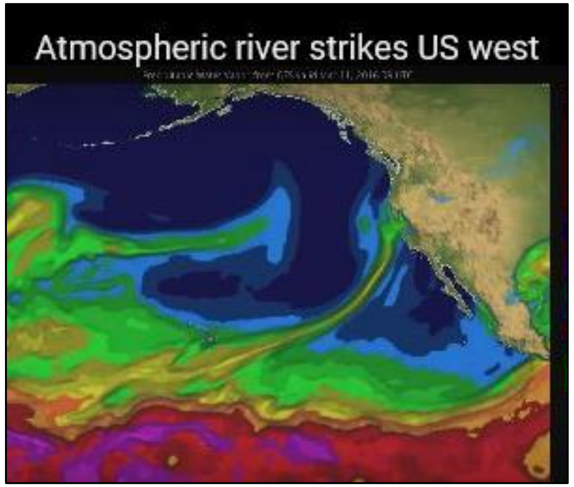
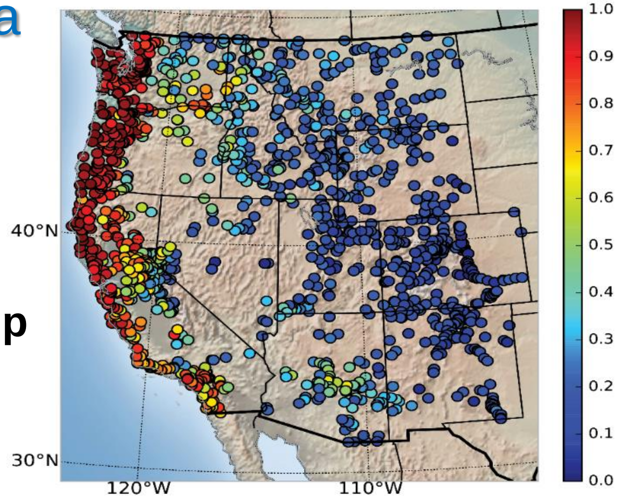
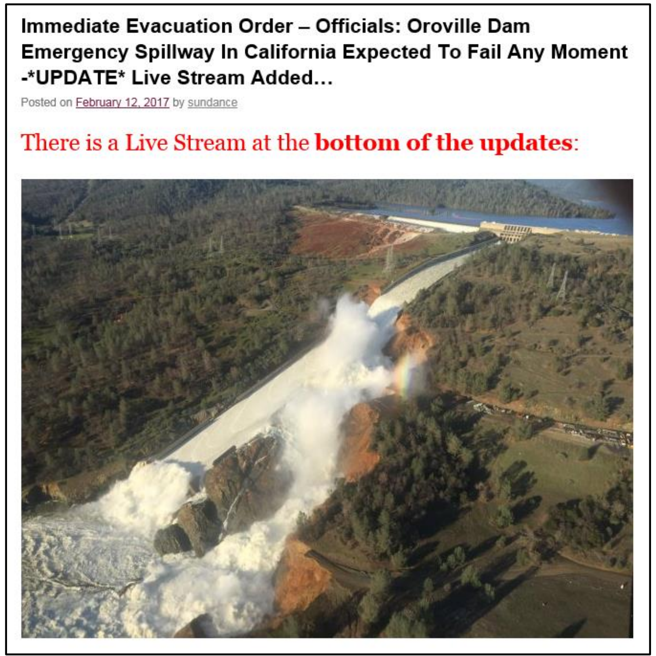


Presented to:
ACWI Water Resources Adaptation to Climate Change Workgroup
September 25, 2018



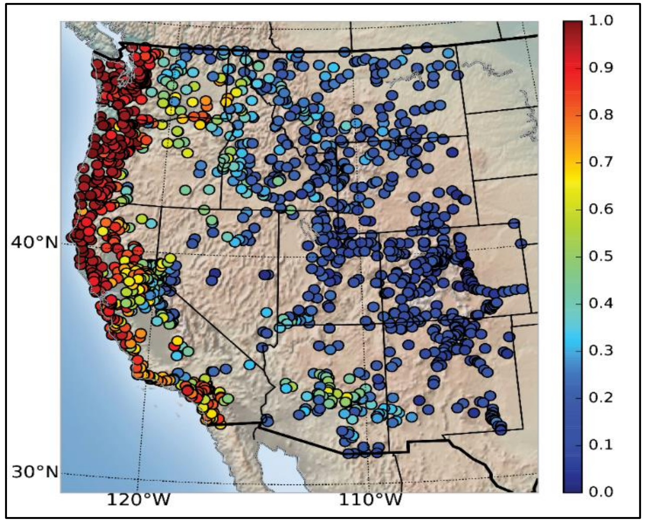

Immediate Evacuation Order – Officials: Oroville Dam Emergency Spillway In California Expected To Fail Any Moment -*UPDATE* Live Stream Added…

Posted on February 12, 2017 by sundance

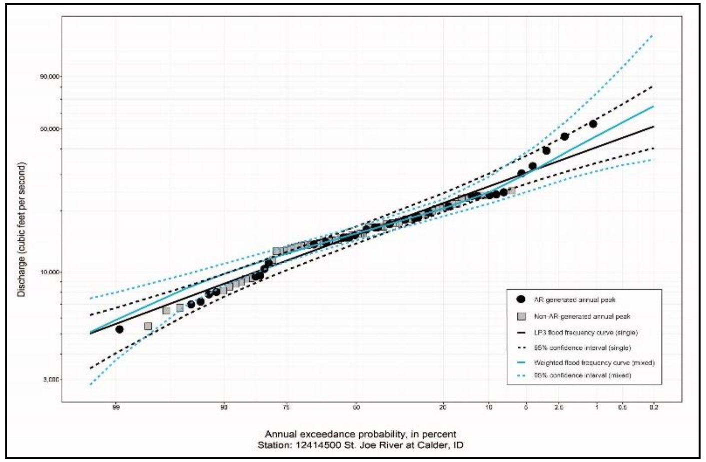
There is a Live Stream at the **bottom of the updates**:

Motivation and objectives

Improving Hazard Assessment
Balancing flood control, water supply and reservoir operations with extreme meteorological events in the western United States



Evaluation of the impacts of **hydrometeorological processes** on flood frequency in the western United States



Methodological developments to account for **mixed populations** in flood frequency analysis

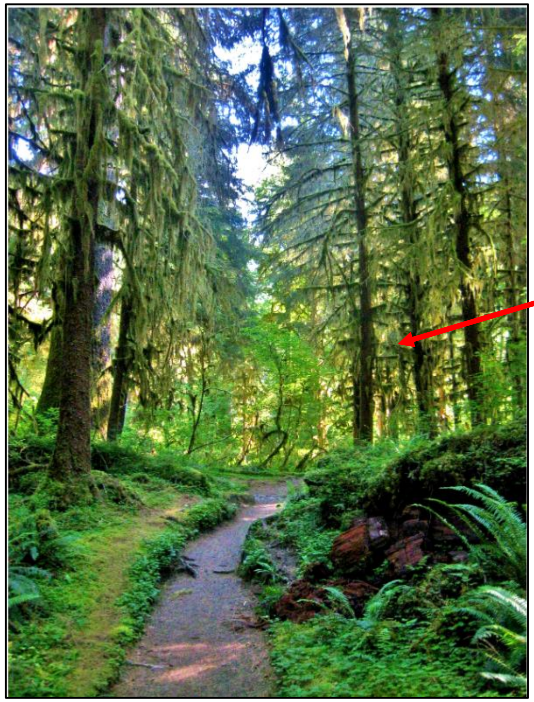
Motivation and objectives

Improving Hazard Assessment

Balancing flood control, water supply and reservoir operations with extreme meteorological events in the western United States

https://theconservativetreehouse.com/2017/02/12/immediate-evacuation-order-officials-oroville-dam-emergency-spillway-in-california-expected-to-fail-any-moment/

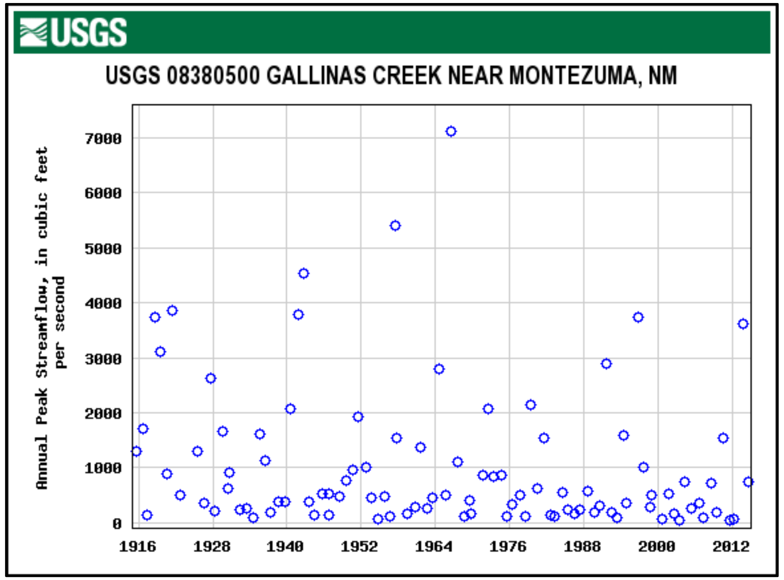
Diverse flood hydrology throughout Western United States



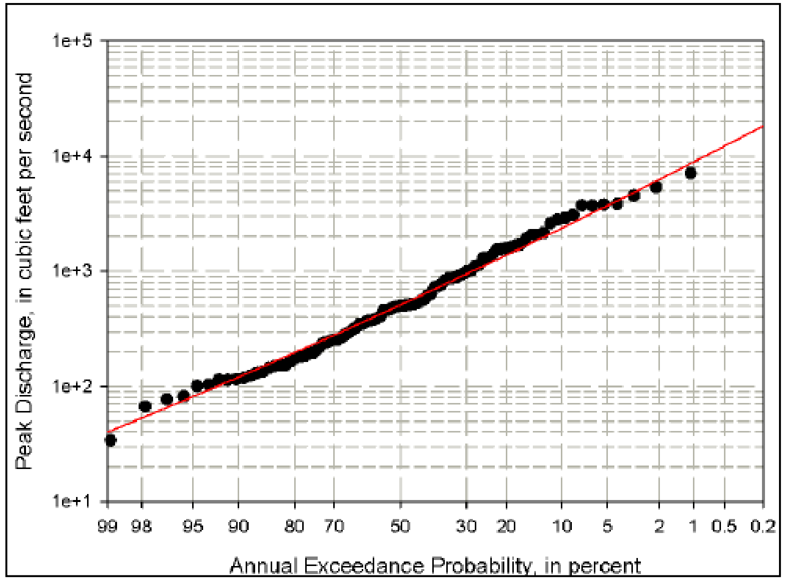
http://exotichikes.com/wp-content/uploads/2014/02/IMG_1449-Large.jpg

http://verdenews.com/SiteImages/Article/30964a.jpg

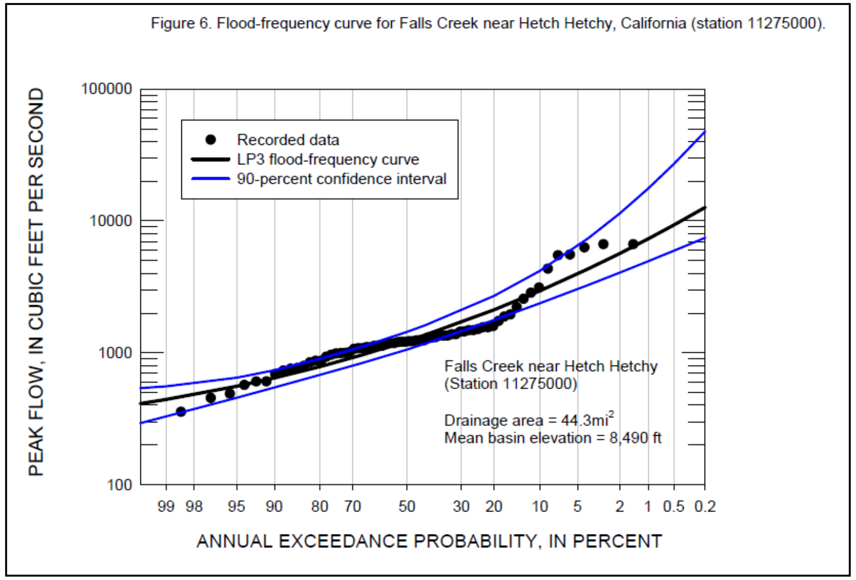
Determining flood frequency at gaged sites—statistical analysis of annual peak discharge



Fit a probability distribution to the sample (recorded) data



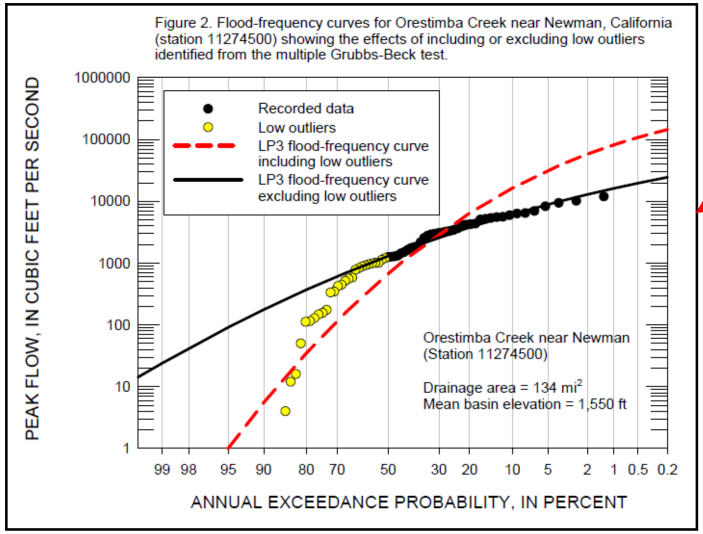
Distribution used in the U.S. is the log Pearson Type III (LP3) (described in Bulletin 17B/B17C)



(Parrett et.al., 2010)

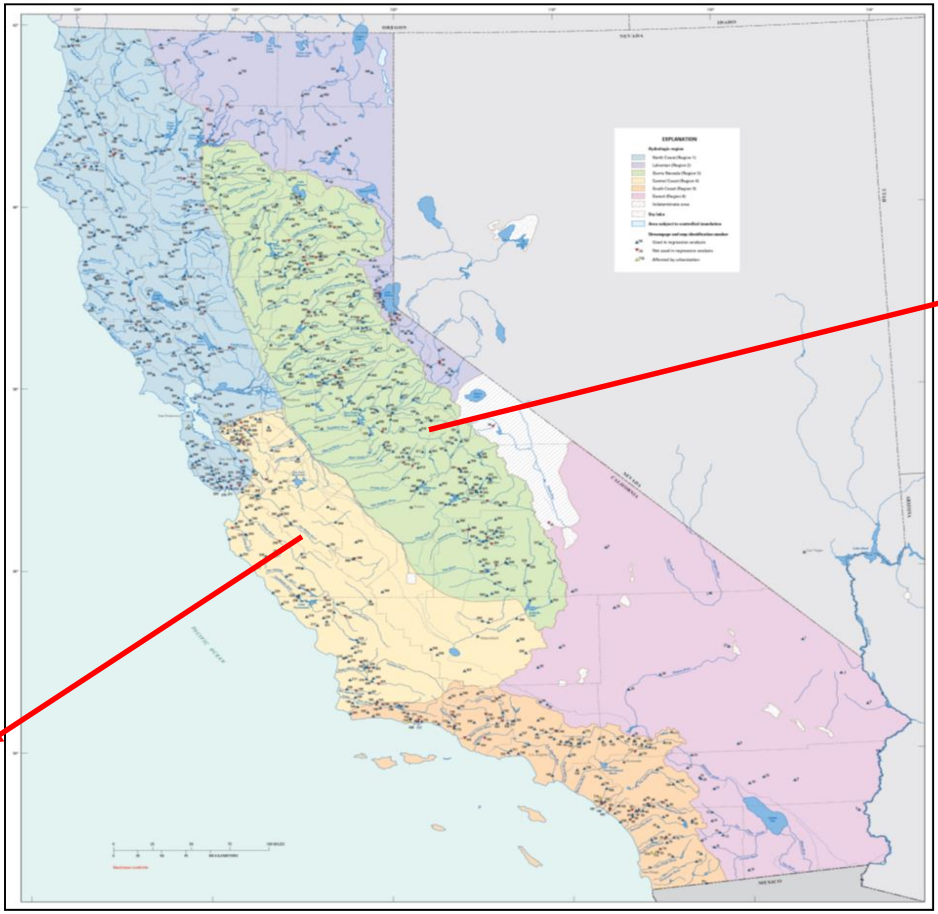
Mixed population site in California

Complicated at-site streamflow data and flood frequency estimates

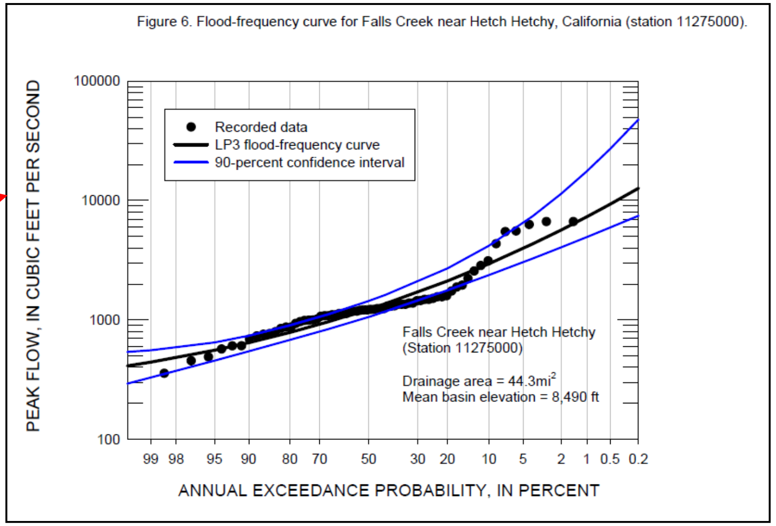


(Gotvald et.al., 2012)

Mixed Populations:
low flood peaks with influence



(Gotvald et.al., 2012)

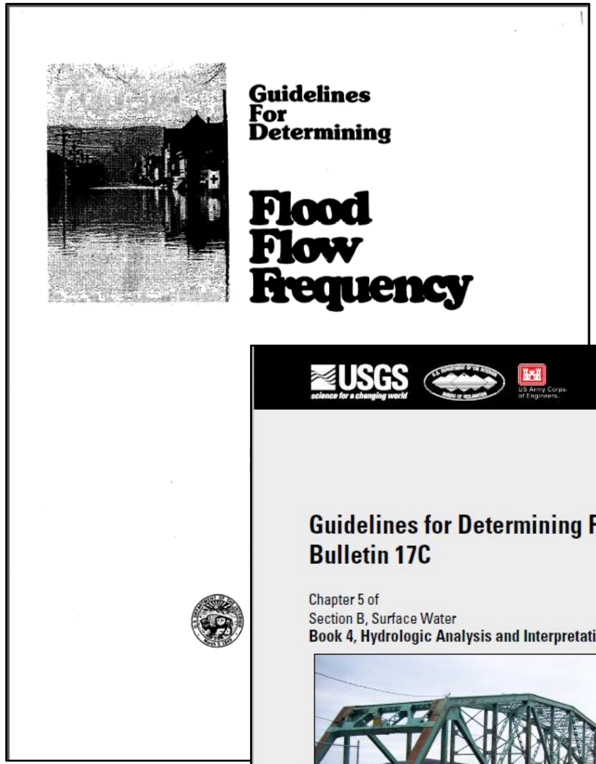


(Parrett et.al., 2010)

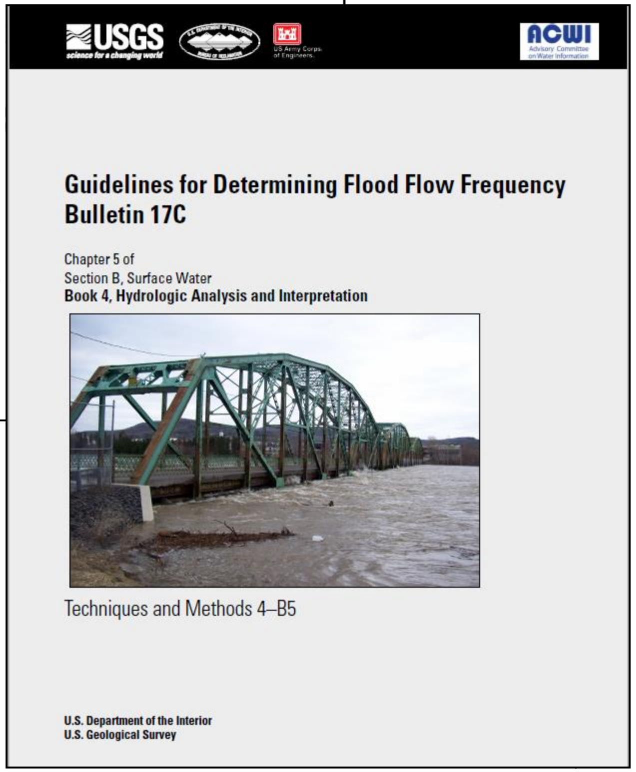
Mixed Populations:
rain-on-snow flood events

“Future Work” (p.27) Bulletin 17B

1. Selection of distribution and fitting procedures.
2. The identification and treatment of mixed distributions.
3. The treatment of outliers both as to identification and computational procedures.
4. Alternative procedures for treating historic data.
5. More adequate computation procedures for confidence limits to the Pearson III distribution.
6. Procedures to incorporate flood estimates from precipitation into frequency analysis.
7. Guides for defining flood potentials for ungaged watershed and watersheds with limited gaging records.
8. Guides for defining flood potentials for watersheds altered by urbanization and by reservoirs.



(IACWD 1982 B17B)



(England 2018 B17C)

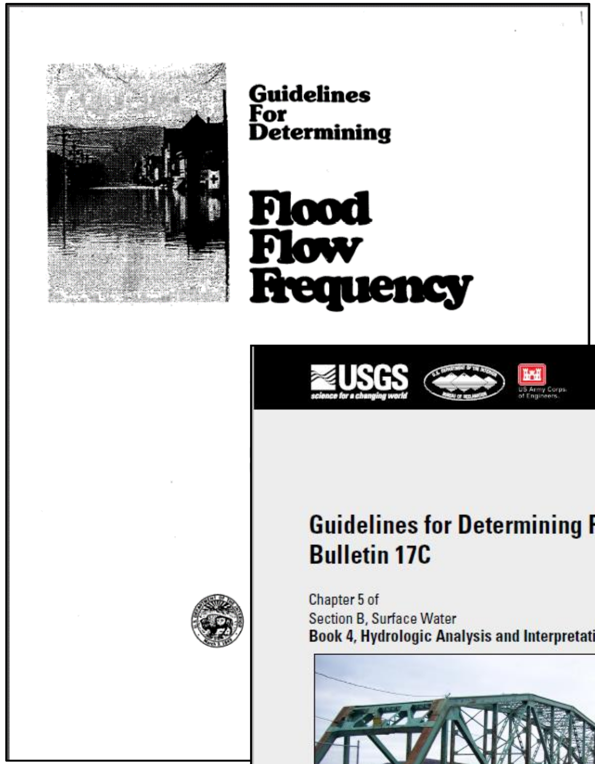
“Future Work” (p.35) Bulletin 17C

1. The identification and treatment of mixed distributions, including those based on hydrometeorological or hydrological conditions;

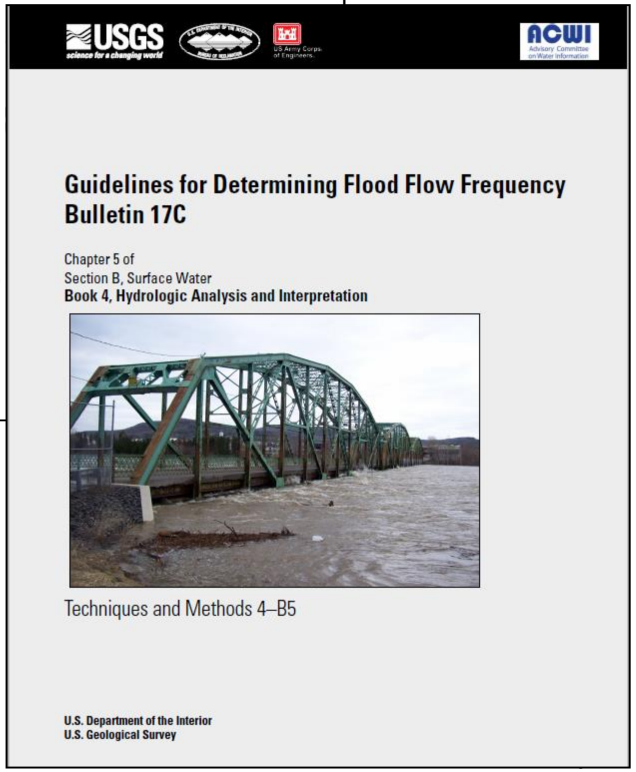
…

6. Guides for estimating dynamic flood frequency curves that vary with time, incorporating climate indices, changing basin characteristics, and addressing potential nonstationary climate conditions;

…



(IACWD 1982 B17B)

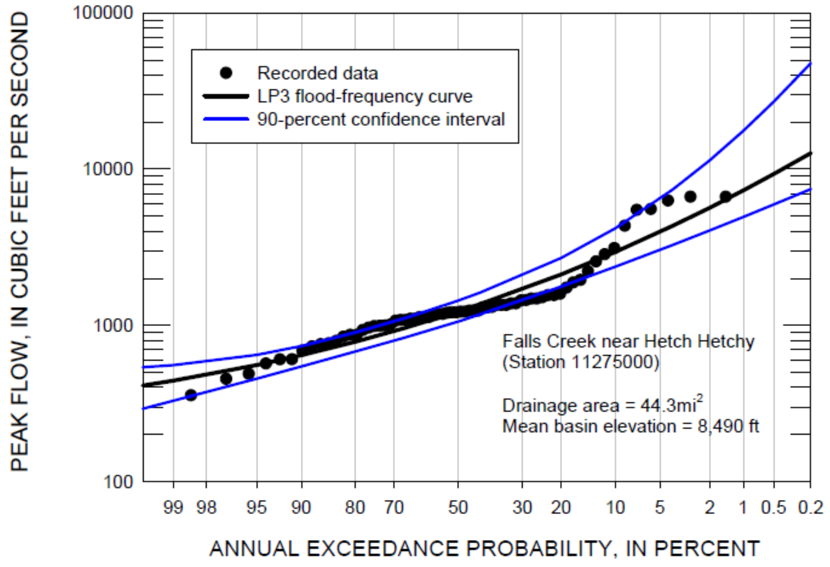


(England 2018 B17C)

Stochastic hydrology and physical processes

“In some circles, however, the obvious fact that **these [annual peak flow] values represent a response to varying processes in the physical world has tended to become less important than the urge to statistically model flood values** in search of the best fit of the observed data and therefore (ideally) the best predictive capability of future flows…” (Hirschboeck, 1988)

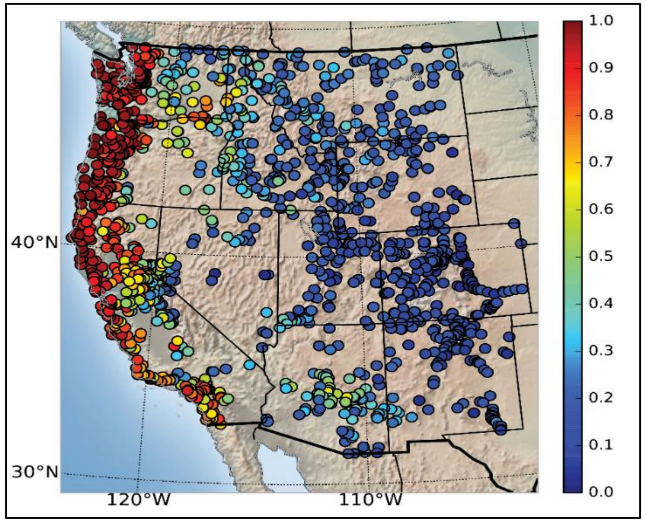
Figure 6. Flood-frequency curve for Falls Creek near Hetch Hetchy, California (station 11275000).

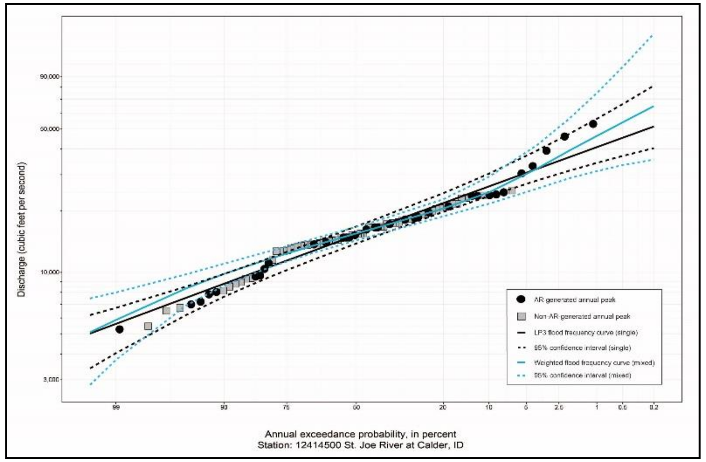


“[T]he main emphasis in stochastic analysis of hydrological processes…has been on the fitting of various preconceived mathematical models to empirical data rather than on arriving at a proper model from the physical nature of the process itself…**Thus what we usually find is not, in fact, statistical hydrology but merely an illustration of statistical and probabilistic concepts by means of hydrologic data**.” (Klemeš, 1974, p.2)

Motivation and objectives

Evaluation of the impacts of **hydrometeorological processes** on flood frequency in the western United States





Evaluation of the impacts of hydrometeorological processes on flood frequency in the western United States

Key questions to be addressed:

- What are the spatial and fractional contributions of atmospheric rivers (ARs) and eastern North Pacific tropical cyclones (TCs) on the annual peak flows throughout the western United States?
- What are the roles of ARs and TCs on the upper tail of the flood peak distribution?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‘Atmospheric river’ storm bringing rain to Southern California

A heavy storm generated by an “atmospheric river” is seen early Friday, Jan. 6, 2017, on this enhanced infrared satellite image. The storm is unusual in that it is approaching from the west and not from the Gulf of Alaska. (National Weather Service)

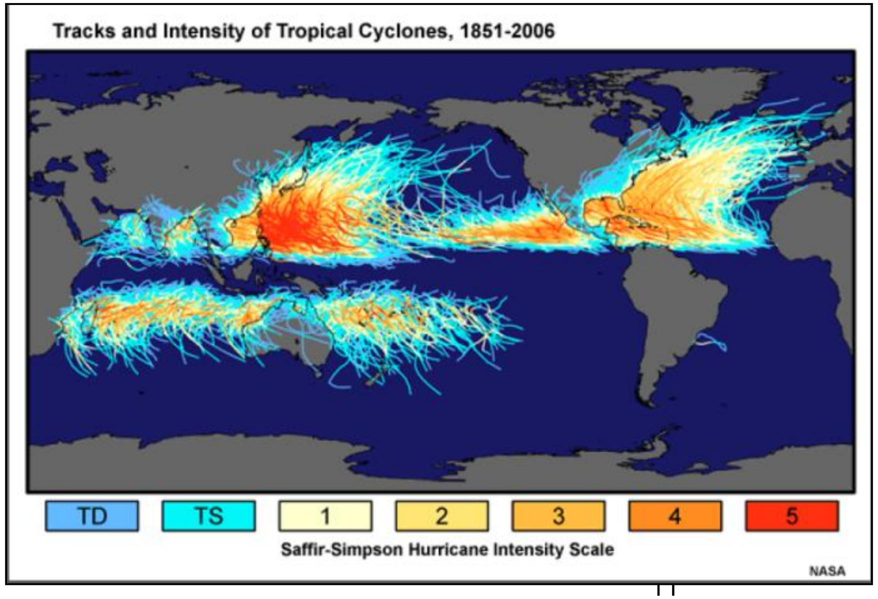
http://www.dailynews.com/general-news/20170106/atmospheric-river-storm-bringing-rain-to-southern-california


Powerful storm causes widespread flooding in Northern California, evacuations in Sonoma County and neighboring Nevada

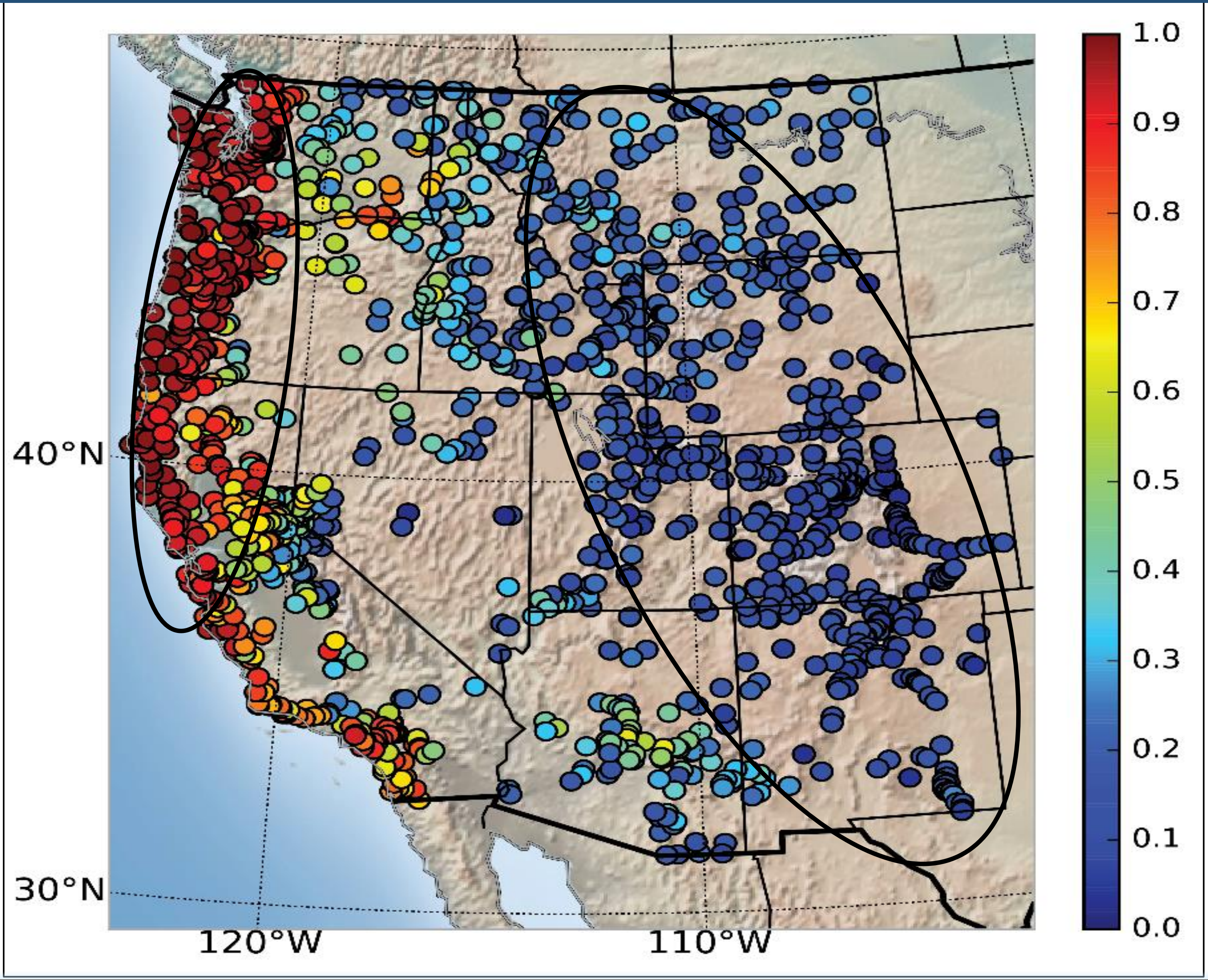
PHOTO GALLERY

Forecasters predict this storm will be the region's most powerful in a decade.

http://www.latimes.com/local/lanow/



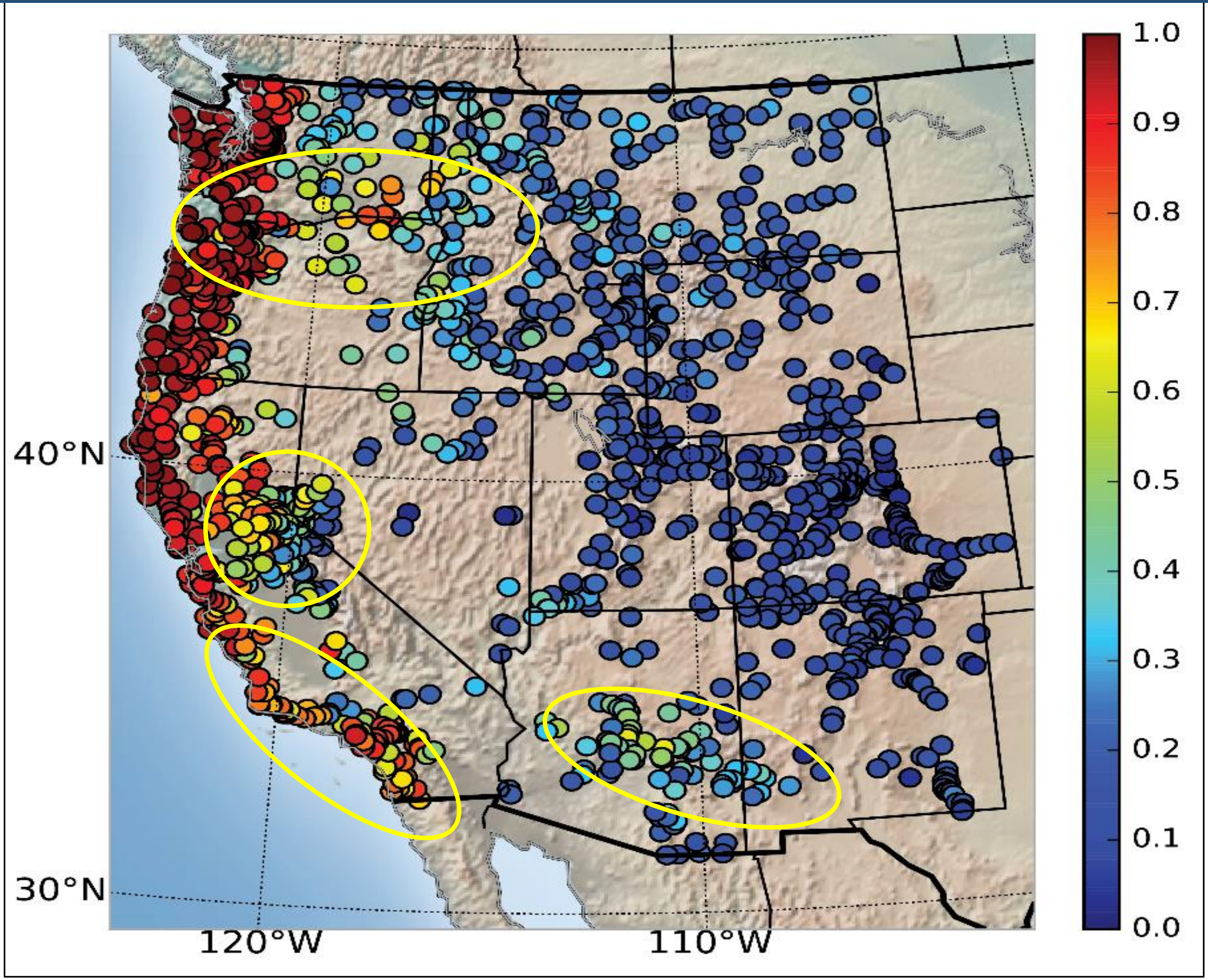
The highest fraction of AR-generated peaks is found in the Pacific Northwest, while peaks in the far inland states are dominated by non-AR events



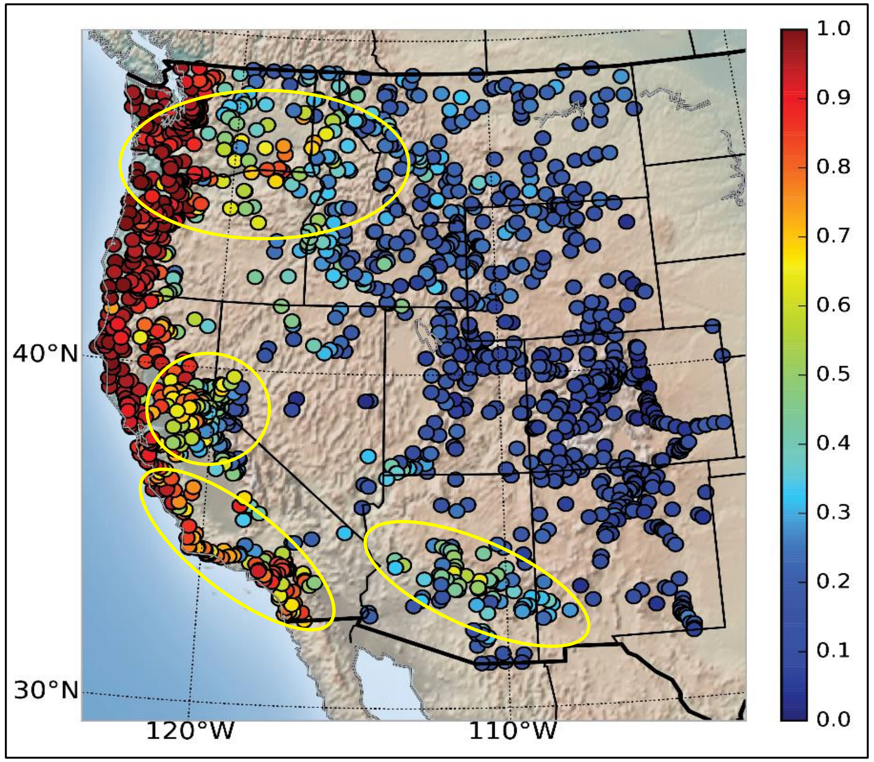
(Modified from Barth et al., 2017)

Barth, N.A., Villarini, G. and White, K., Mixed populations and annual flood frequency estimates in the western United States: The role of atmospheric rivers, *Water Resources Research,* 2017.

There are four smaller regions with a mixture of ~30-70% AR and non-AR-generated flood peaks



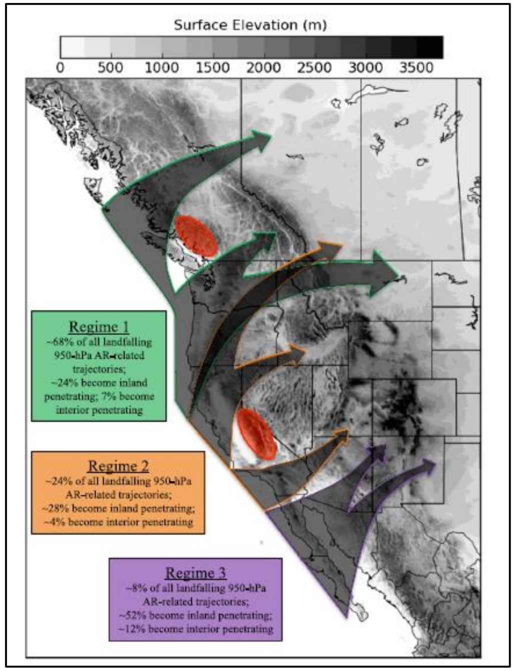
These results are consistent with other studies that showed similar flood seasonality and patterns of AR inland penetration



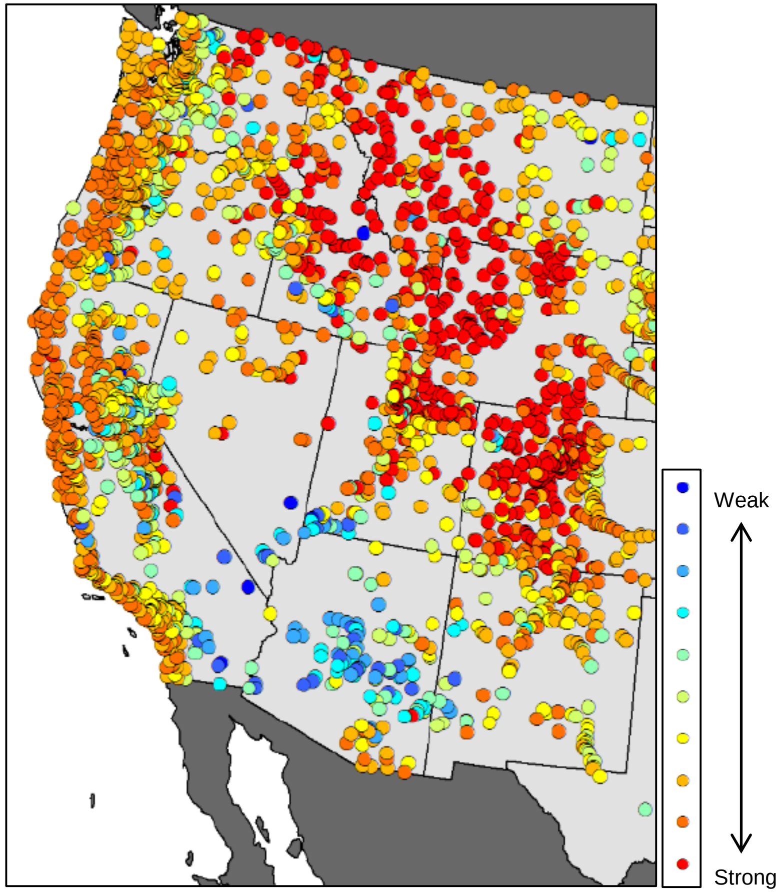
(Rutz et al., 2015)

Pathways for ARs and spatial fractional contribution of ARs to annual peak flow data:

- **Landfalling**
- **Interior penetrating**
- **Inland penetrating**



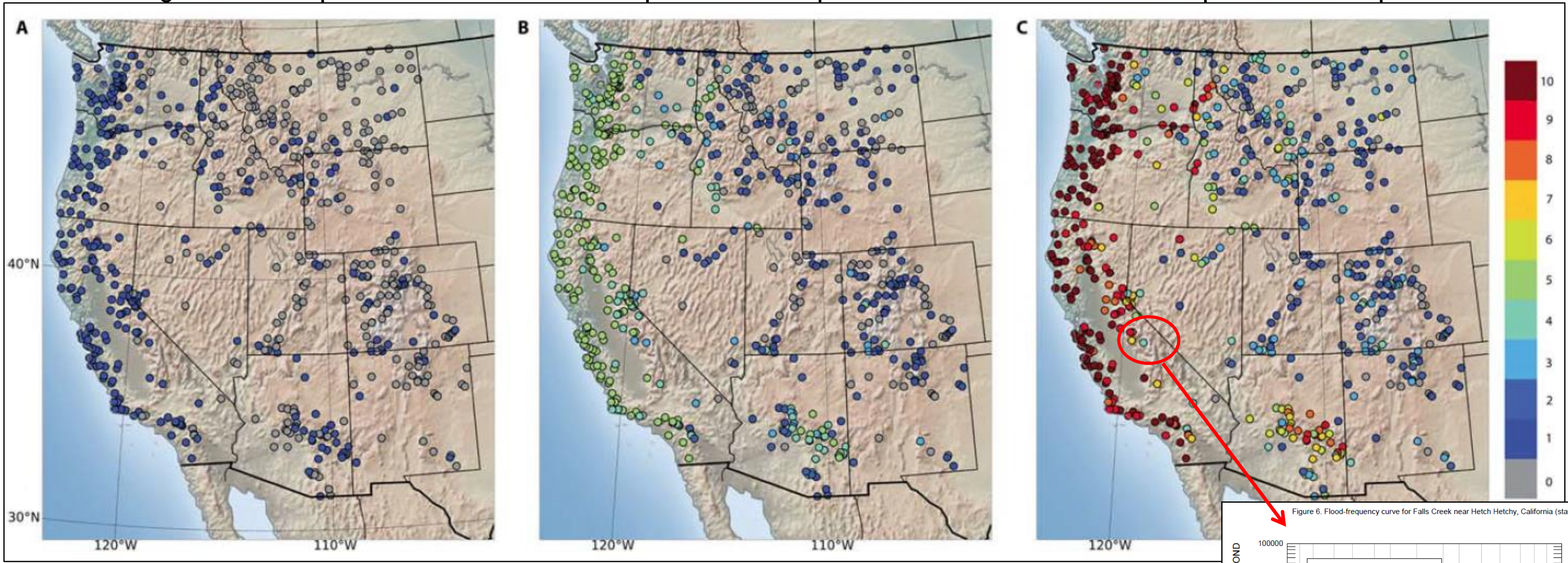
Strength of seasonality

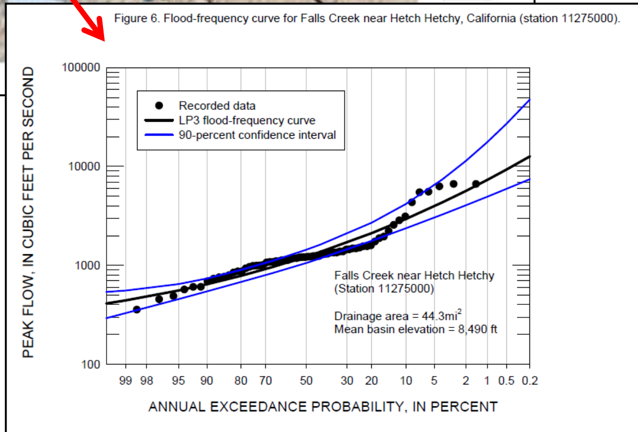


(Modified from Villarini, 2016)

Many of the largest flood peaks are associated with ARs along the U.S. West Coast, with large spatial variability

Largest annual peak | Top-five annual peaks | Top-ten annual peaks





Regional contribution of precipitation from TCs in the southwestern United States spanning 1958-2003

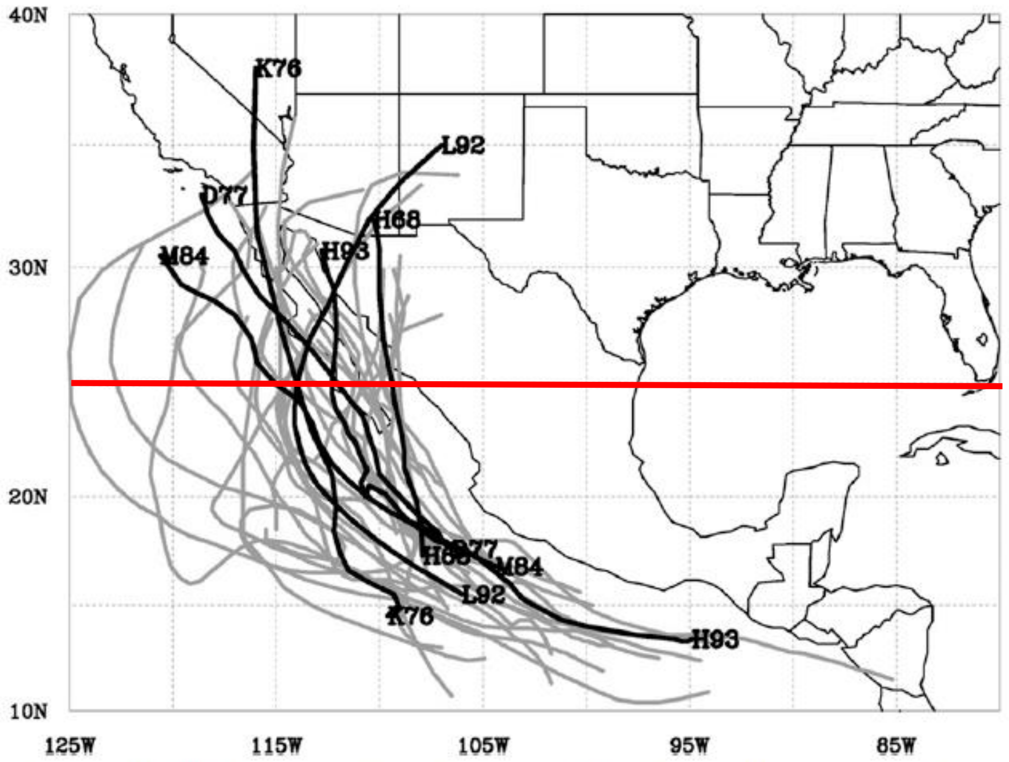


FIG. 3. NHC/TPC best tracks of the 35 eastern North Pacific tropical cyclones that affected the southwest United States. The tracks in black are the storms for which precipitation distributions are shown in Figs. 8 and 10. The tracks are labeled by the first letter of the storm's name and the last two digits of the storm's year as listed in Table 1.

(Corbosiero et al., 2009)

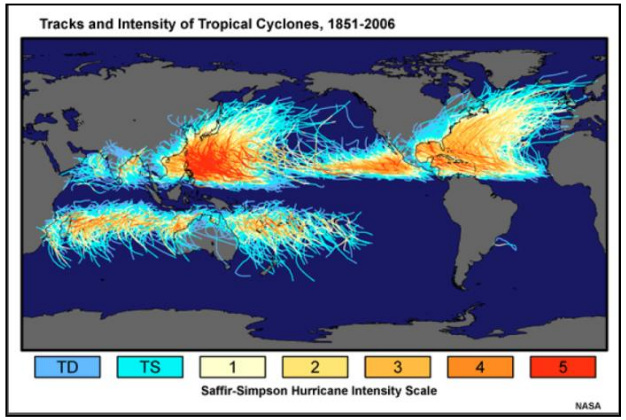
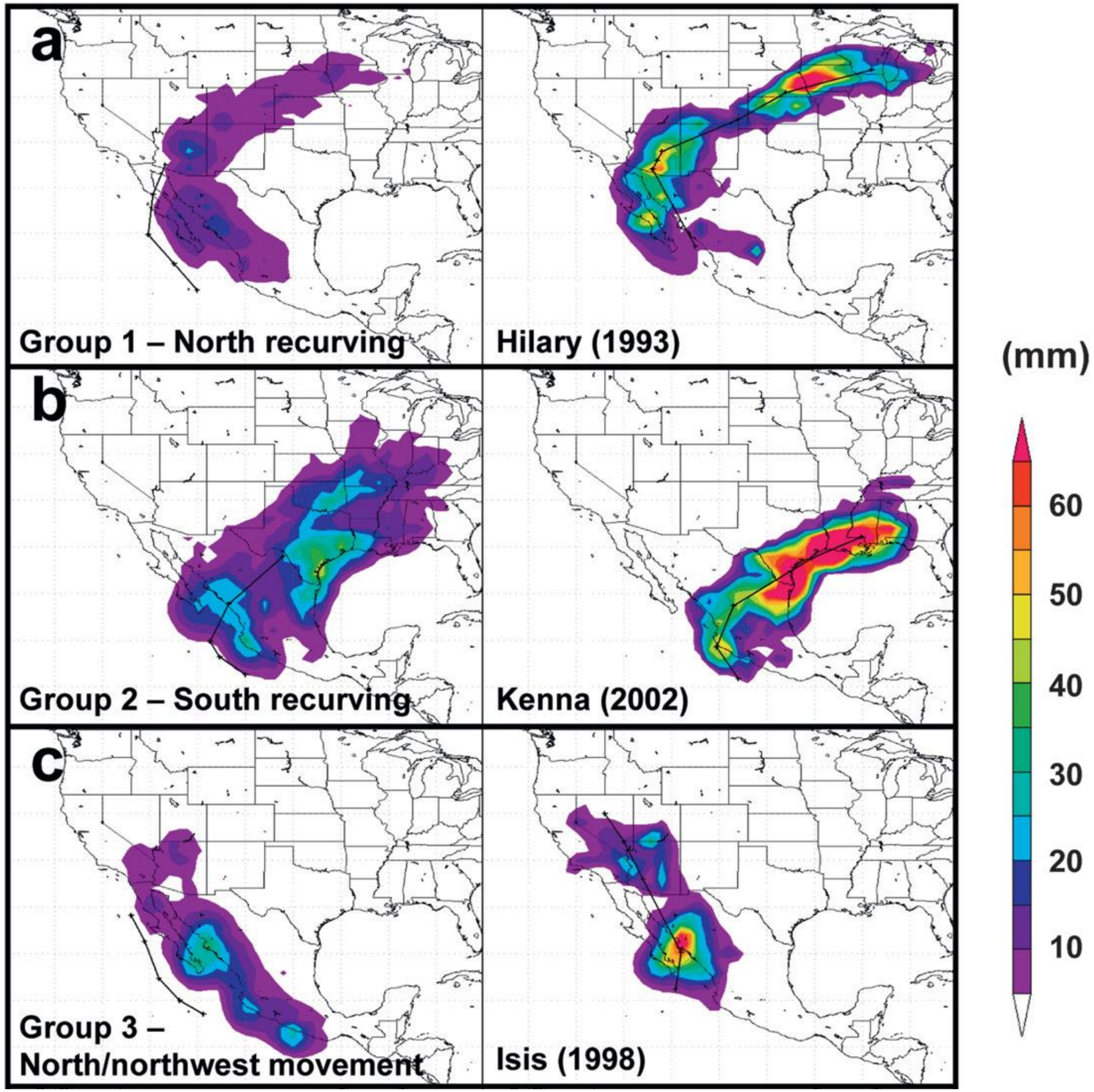


TABLE 1. Eastern Pacific TCs that affected the southwest United States. The dates on which precipitation associated with the TC fell in the southwest, the precipitation distribution category (see text for definitions), and states that received greater than 25% of their warm-season (16 Jun–15 Oct) precipitation from the TC are given in the last three columns.

Year	Storm name	Dates	Precipitation distribution category	State(s) receiving >25% of warm-season precipitation
1958	TS 10	10–14 Sep	SW–NE swath	AZ CO NM UT
	H 11	4–6 Oct	SW–NE swath	AZ
1959	H 10	11–15 Sep	CA–NV track	AZ CA NV
1960	H Diana	19–23 Aug	Weakening in situ	AZ CO
1962	TS Claudia	22–26 Sep	SW–NE swath	AZ CA NM NV
1963	TS Jen-Kath	17–21 Sep	CA–NV track	AZ CA NV UT
1965	H Emily	4–7 Sep	Weakening in situ	CA UT
1966	H Kirsten	28 Sep–2 Oct	Weakening in situ	—
1967	H Katrina	1–5 Sep	CA–NV track	AZ CA NV
1968	TS Hyacinth	19–21 Aug	Weakening in situ	AZ
	H Pauline	2–5 Oct	SW–NE swath	AZ CA NM UT
1970	TS Norma	3–7 Sep	SW–NE swath	AZ CO NM UT
1971	H Olivia	29 Sep–1 Oct	SW–NE swath	AZ CA CO NM UT
1972	H Hyacinth	6–10 Sep	Weakening in situ	CA CO
	H Joanne	5–7 Oct	SW–NE swath	AZ CA CO NM NV UT
1976	H Kathleen	10–12 Sep	CA–NV track	AZ CA NV
	H Liza	1–3 Oct	CA–NV track	NV UT
1977	H Doreen	15–18 Aug	CA–NV track	AZ CA CO NM NV UT
	TS Glenda	26–28 Sep	SW–NE swath	AZ
	H Heather	6–8 Oct	Weakening in situ	AZ CA
1982	H Olivia	24–28 Sep	CA–NV track	CA NV UT
1983	H Manuel	18–20 Sep	Weakening in situ	CA
1984	H Marie	9–12 Sep	Weakening in situ	AZ CA NV
	H Norbert	25–27 Sep	SW–NE swath	—
1986	H Newton	23–26 Sep	SW–NE swath	AZ CA CO NV UT
1989	H Raymond	4–6 Oct	SW–NE swath	AZ NM
1992	H Lester	21–25 Aug	SW–NE swath	AZ CA CO NM NV UT
1993	H Hilary	26–30 Aug	SW–NE swath	AZ CA CO NM NV UT
1995	H Ismael	14–16 Sep	SW–NE swath	NM
1996	H Fausto	14–16 Sep	Weakening in situ	AZ UT
1997	H Nora	24–27 Sep	CA–NV track	AZ CA NV
1998	H Isis	3–7 Sep	CA–NV track	AZ CA NV UT
1999	H Hilary	22–24 Sep	SW–NE swath	AZ CA NV
2003	H Ignacio	26–29 Aug	Weakening in situ	AZ CA CO NM
	H Marty	24–26 Sep	Weakening in situ	AZ

Regional contribution of precipitation from TCs and their remnants in the southwestern United States spanning 1992-2005



(Modified from Ritchie et al., 2011)

TABLE 1. Categories of eastern North Pacific TCs into their common rainfall swath and track types. H = hurricane; TS = tropical storm.

	TC name	Dates
Group 1 (11)	1992 H Darby	6–9 Jul
	1992 H Lester	22–26 Aug
	1993 H Hilary	24–30 Aug
	1994 TS Hector	7–11 Aug
	1998 TS Frank	7–10 Aug
	1999 H Greg	8–13 Sep
	2000 H Carlotta	23–27 Jun
	2001 TS Ivo	13–14 Sep
	2004 TS Blas	13–19 Jul
	2004 H Howard	2–7 Sep
	2004 H Javier	16–21 Sep
Group 2 (8)	1993 H Lidia	11–14 Sep
	1995 H Ismael	13–16 Sep
	1996 H Fausto	12–17 Sep
	1996 H Hernan	3–5 Oct
	1997 TS Olaf/H Pauline	10–14 Oct
	1998 H Madeline	16–20 Oct
	2002 H Kenna	24–28 Oct
	2003 H Nora/H Olaf	6–10 Oct
Group 3 (8)	1993 H Calvin	7–10 Jul
	1997 H Nora	23–26 Sep
	1998 H Isis	2–6 Sep
	1999 H Hilary	20–24 Sep
	2000 H Lane	11–15 Sep
	2001 H Flossie	27 Aug–2 Sep
	2001 H Juliette	23 Sep–4 Oct
	2002 H Hernan	7–8 Sep
Group 4 (8)	1994 H Ileana	12–13 Aug
	1997 TS Carlos	27–28 Jun
	1998 TS Javier	12–15 Sep
	2000 TS Ileana	14–15 Aug
	2000 TS Miriam	16–19 Sep
	2000 TS Norman	22–23 Sep
	2002 TS Genevieve	29 Aug–1 Sep
	2005 H Otis	29 Sep–4 Oct
Group 5 (6)	1994 H Rosa	12–17 Oct
	1995 H Flossie	11–13 Aug
	1997 TS Ignacio	18–20 Aug
	2000 TS Bud	14–19 Jun
	2003 H Ignacio	25–29 Aug
	2003 H Marty	22–26 Sep

Contribution of precipitation from TCs within a 500 kilometer radius in the southwestern United States spanning 1970-2014

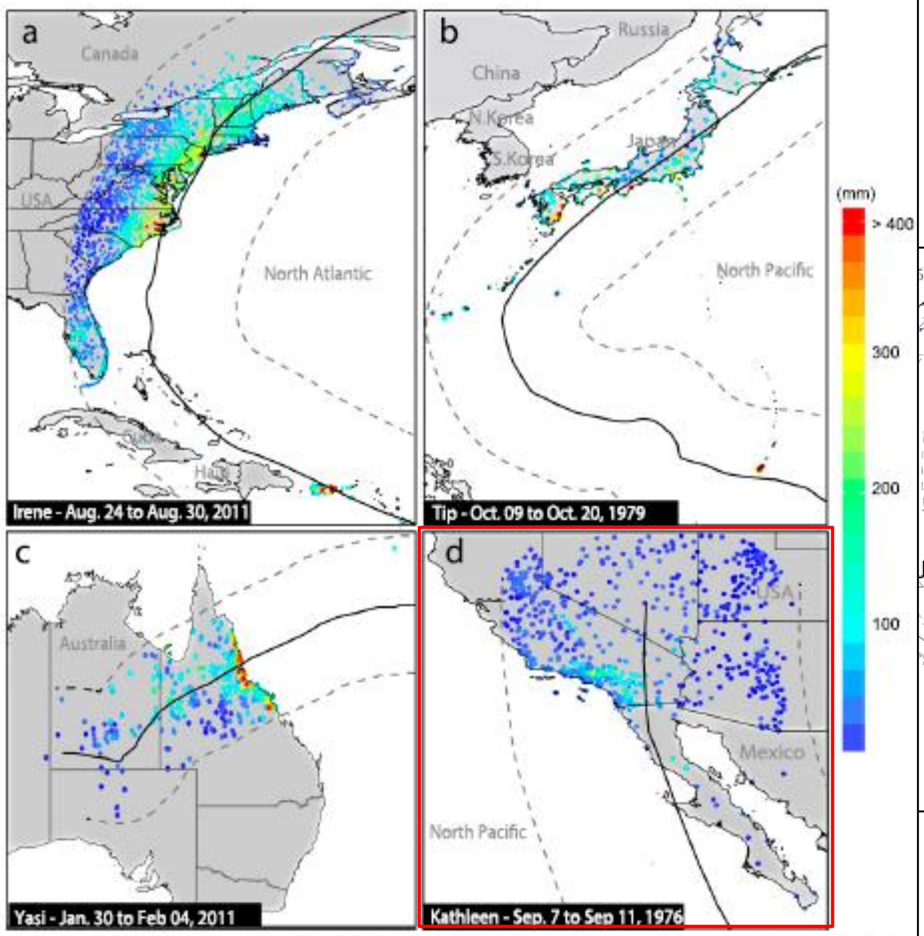
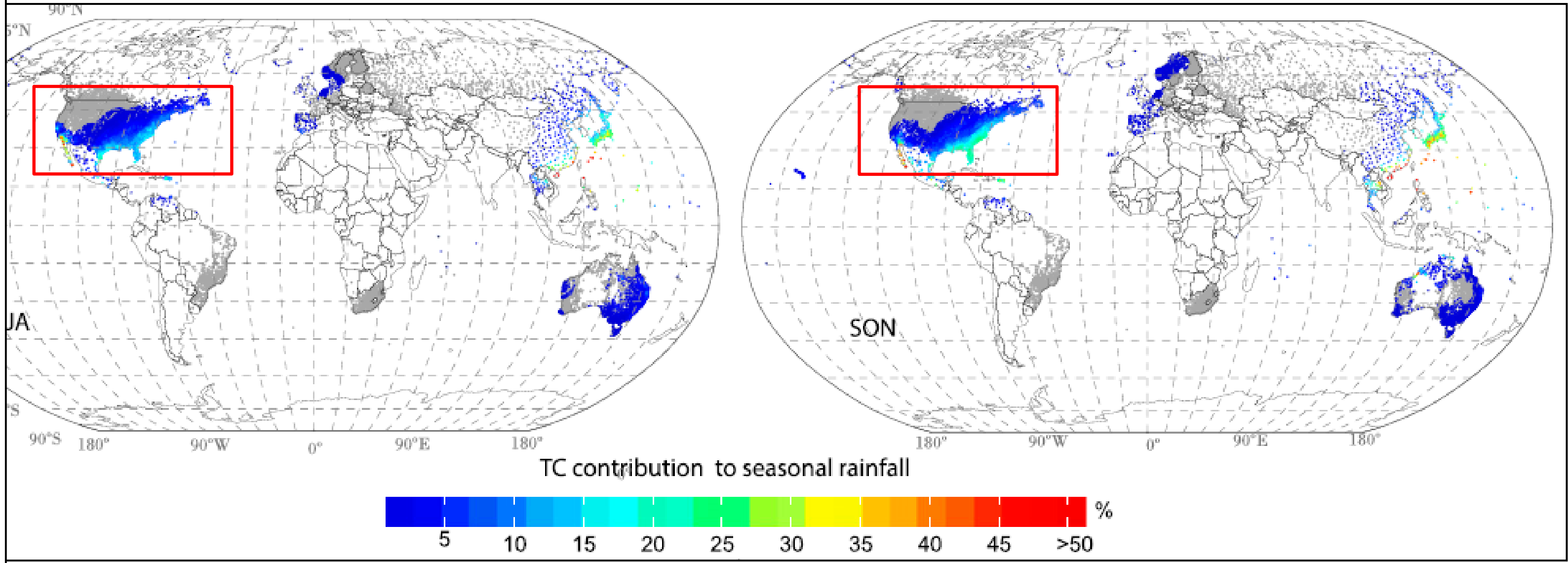
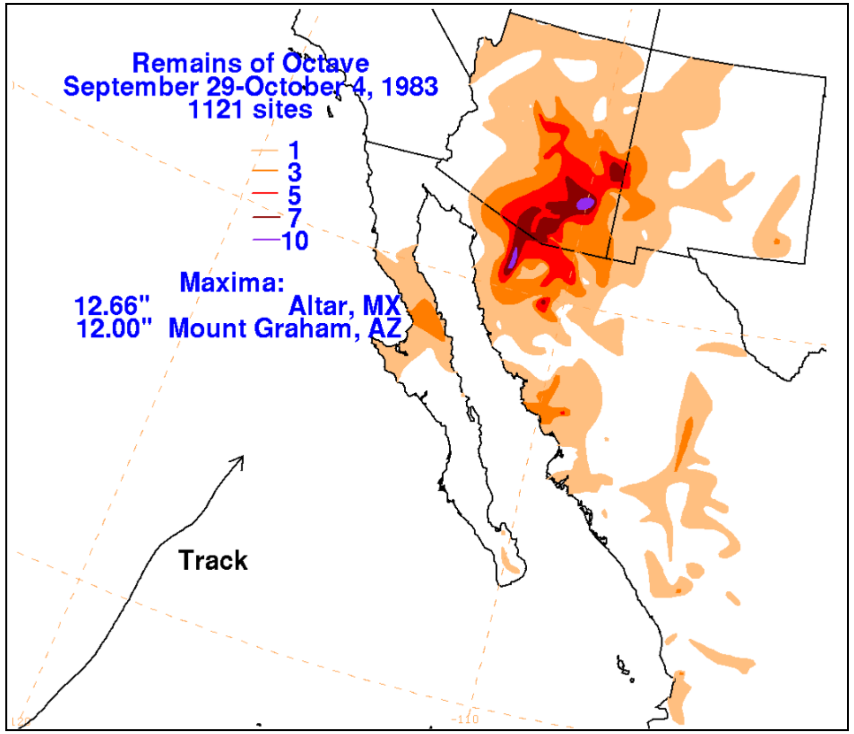


FIG. 1. (a)–(d) Examples of TCs and their induced rainfall totals (mm). Each panel shows the TC track (black line) and the recorded amount of rain (colors) at stations located within 500 km (dashed line) from the center of each storm track.

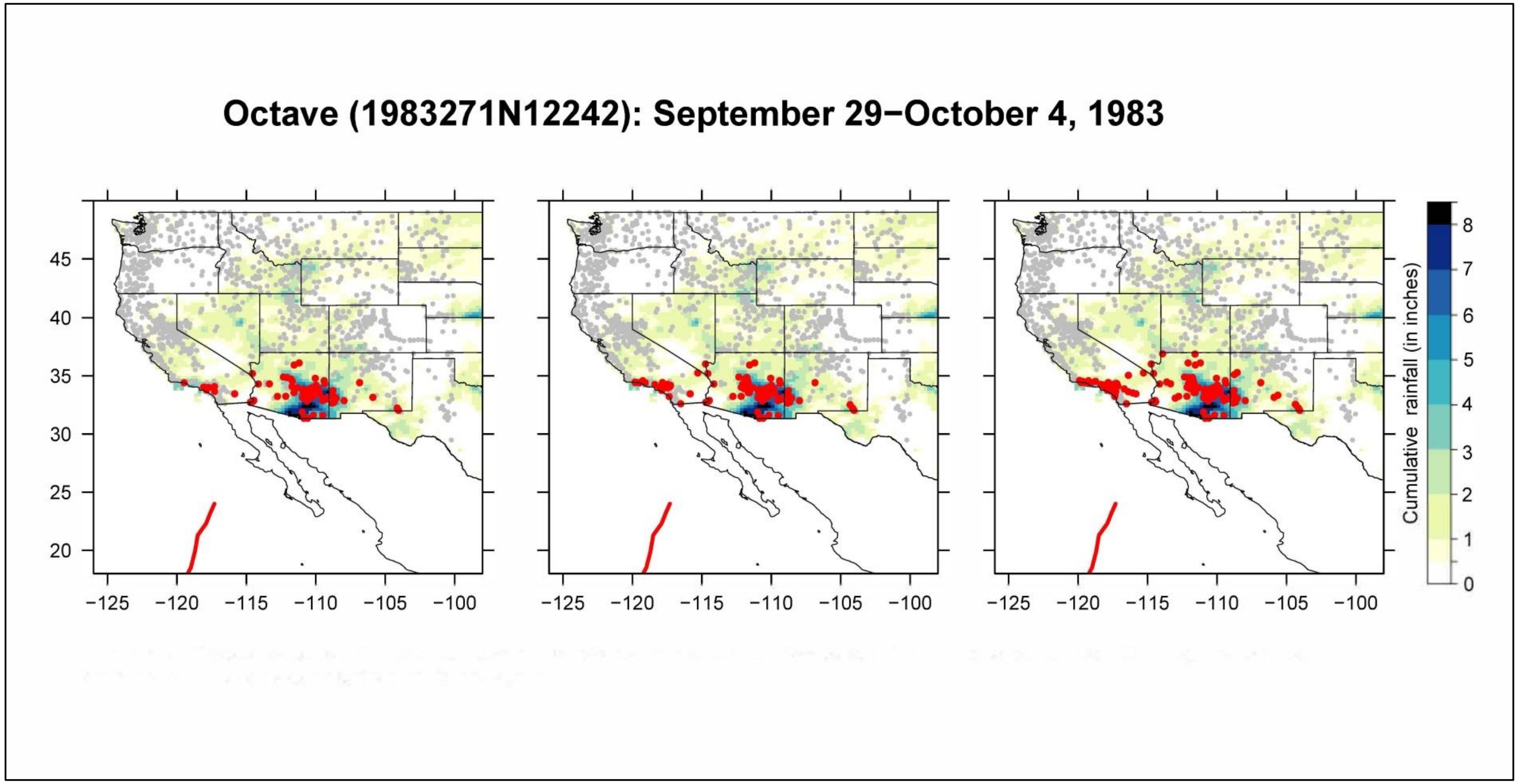


(Modified from Khouakhi et al., 2017)

Relationship between cumulative precipitation and annual maxima attributed to TCs and their remnants in the western United States

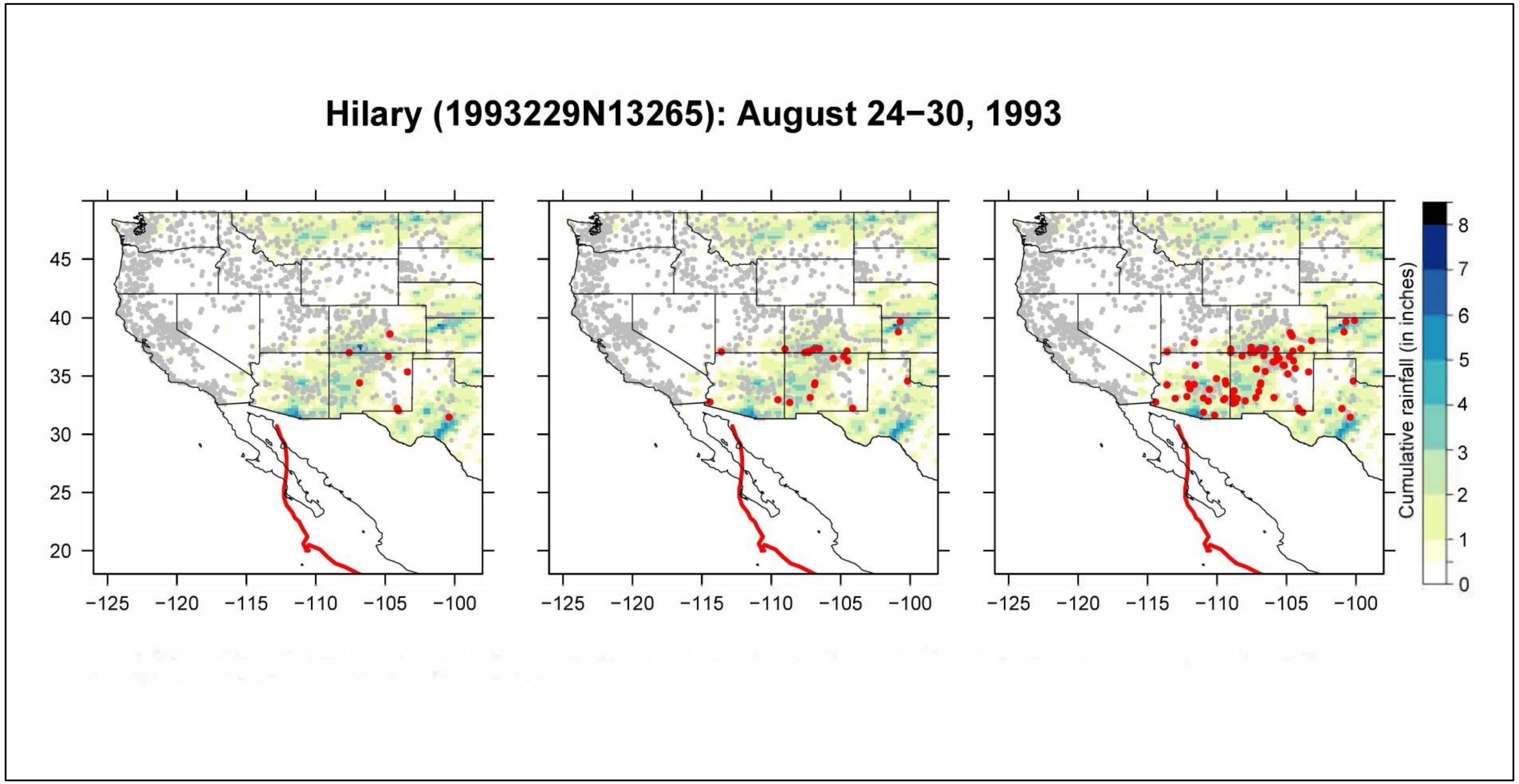


(NOAA-WPC; (http://www.wpc.ncep.noaa.gov/tropical/rain/tcpointofentry.html);

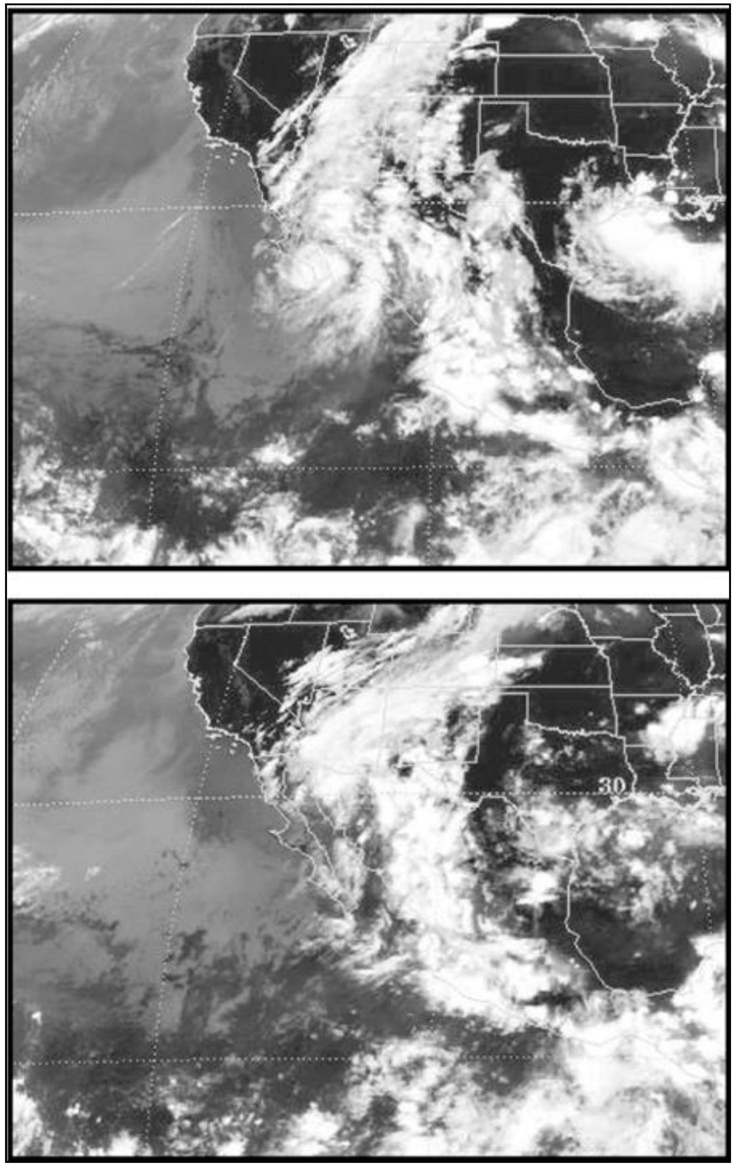


Barth, N.A., Villarini, G. and White, K., Contribution of Eastern North Pacific Tropical Cyclones and Their Remnants on Flooding in the Western United States, International *Journal of Climatology,* 2018.

Cumulative precipitation and annual maxima attributed to a TC-event

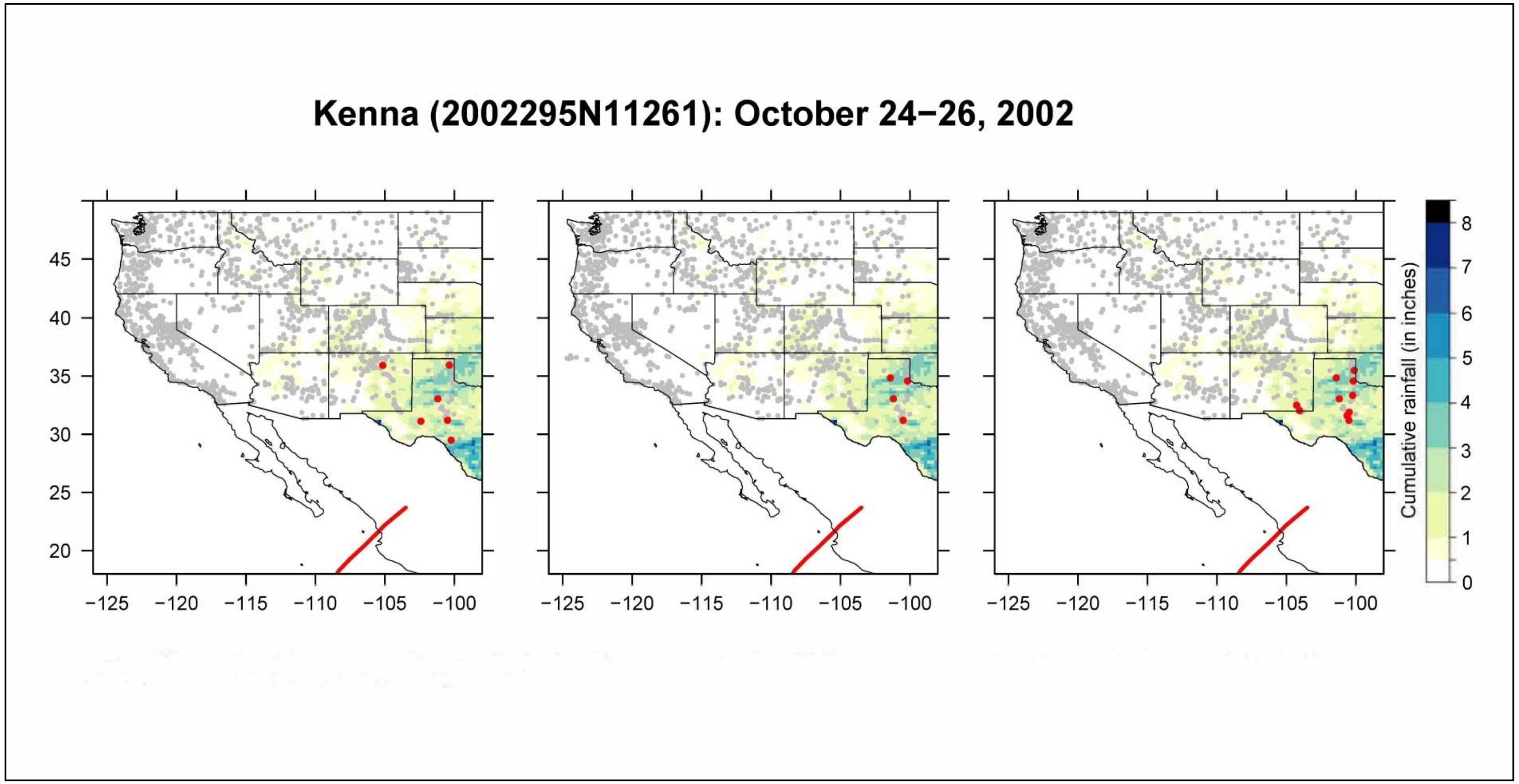


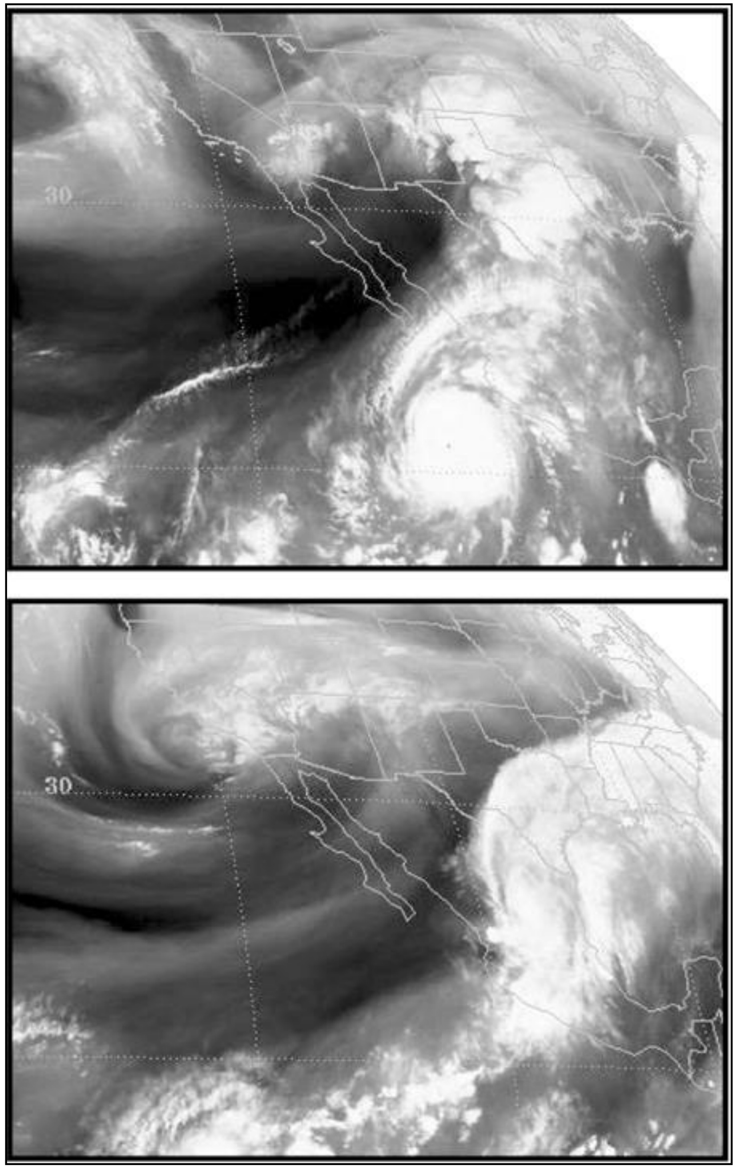
(Barth et al., 2018)



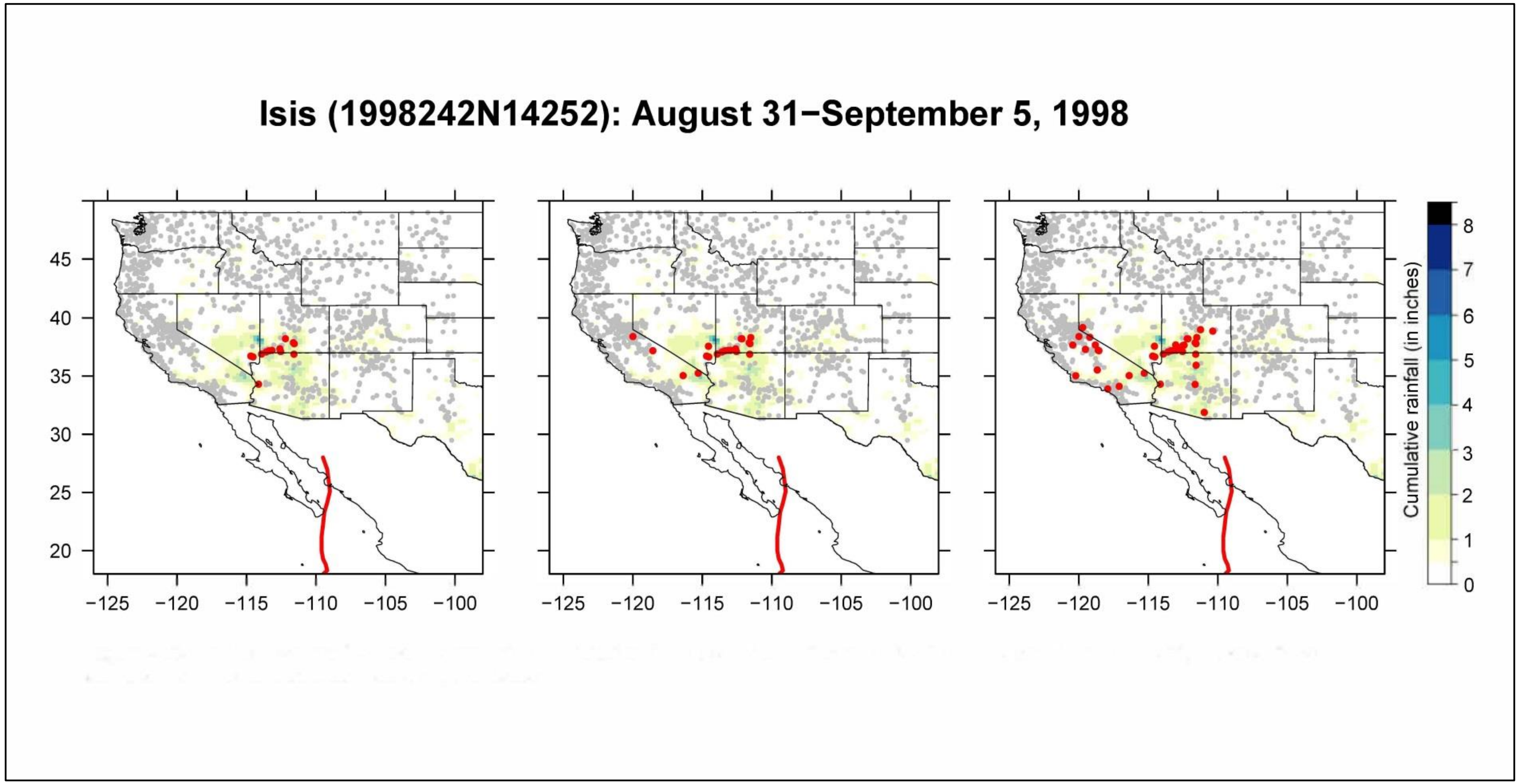
(Modified from Ritchie et al., 2011)

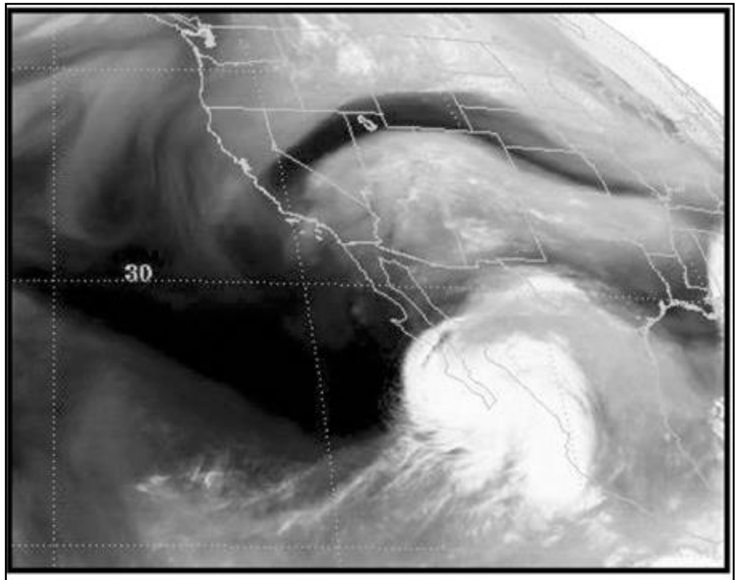
Cumulative precipitation and annual maxima attributed to a TC-event

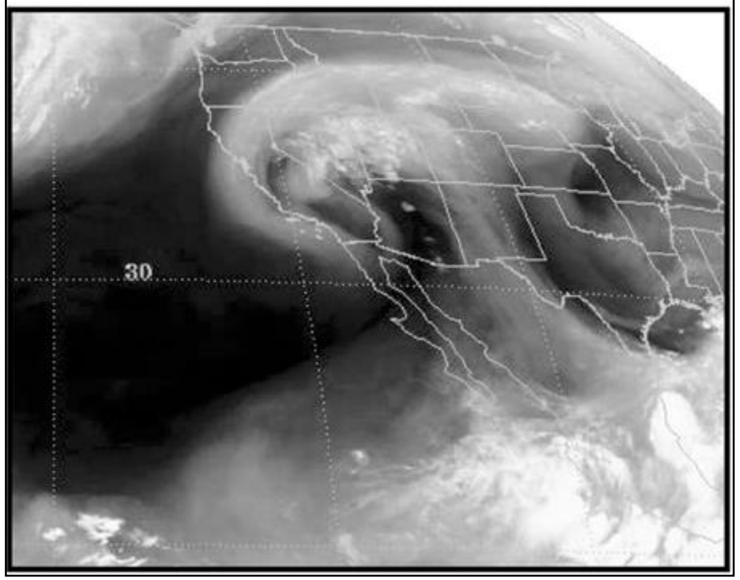




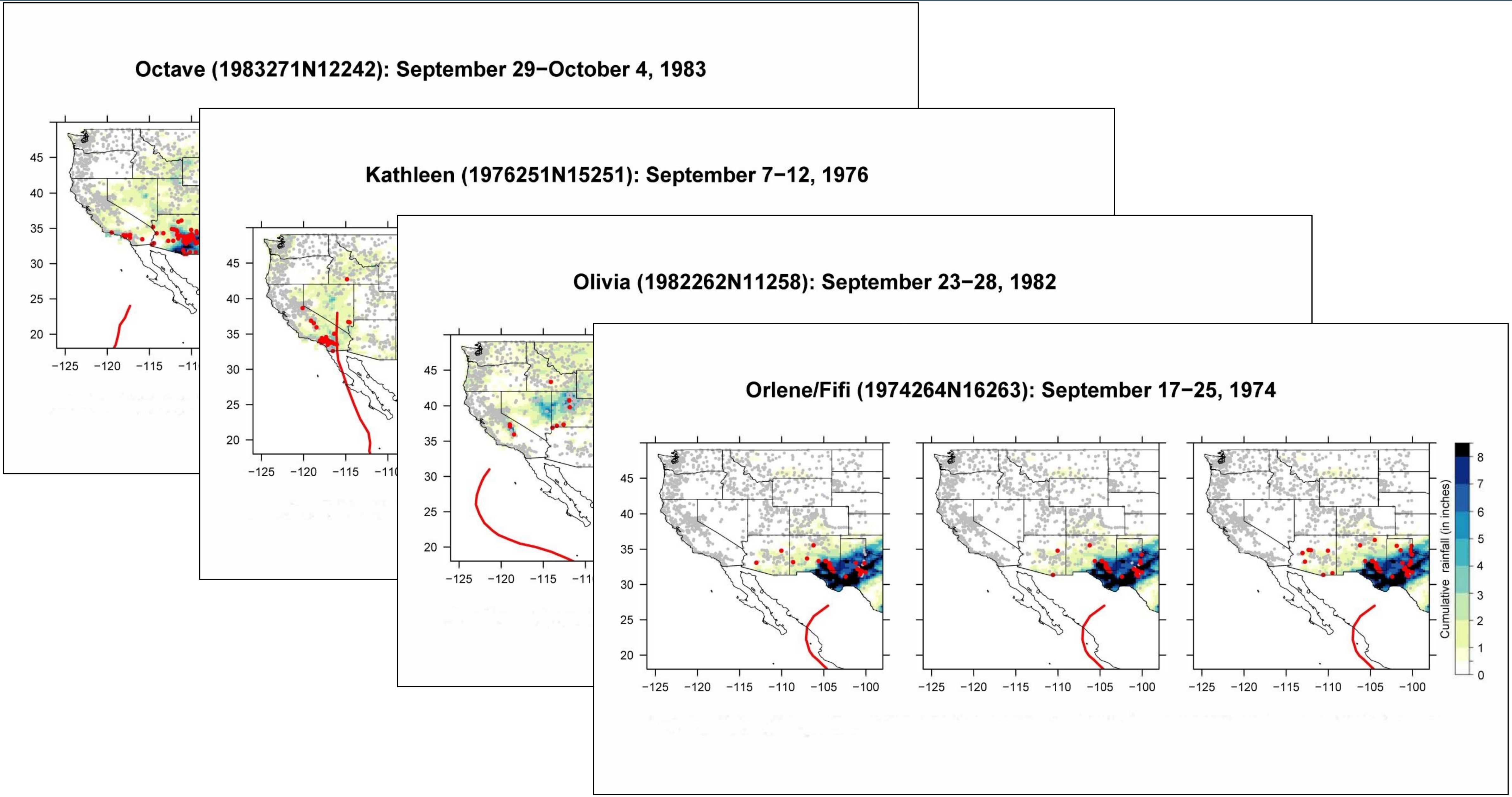
Cumulative precipitation and annual maxima attributed to a TC-event



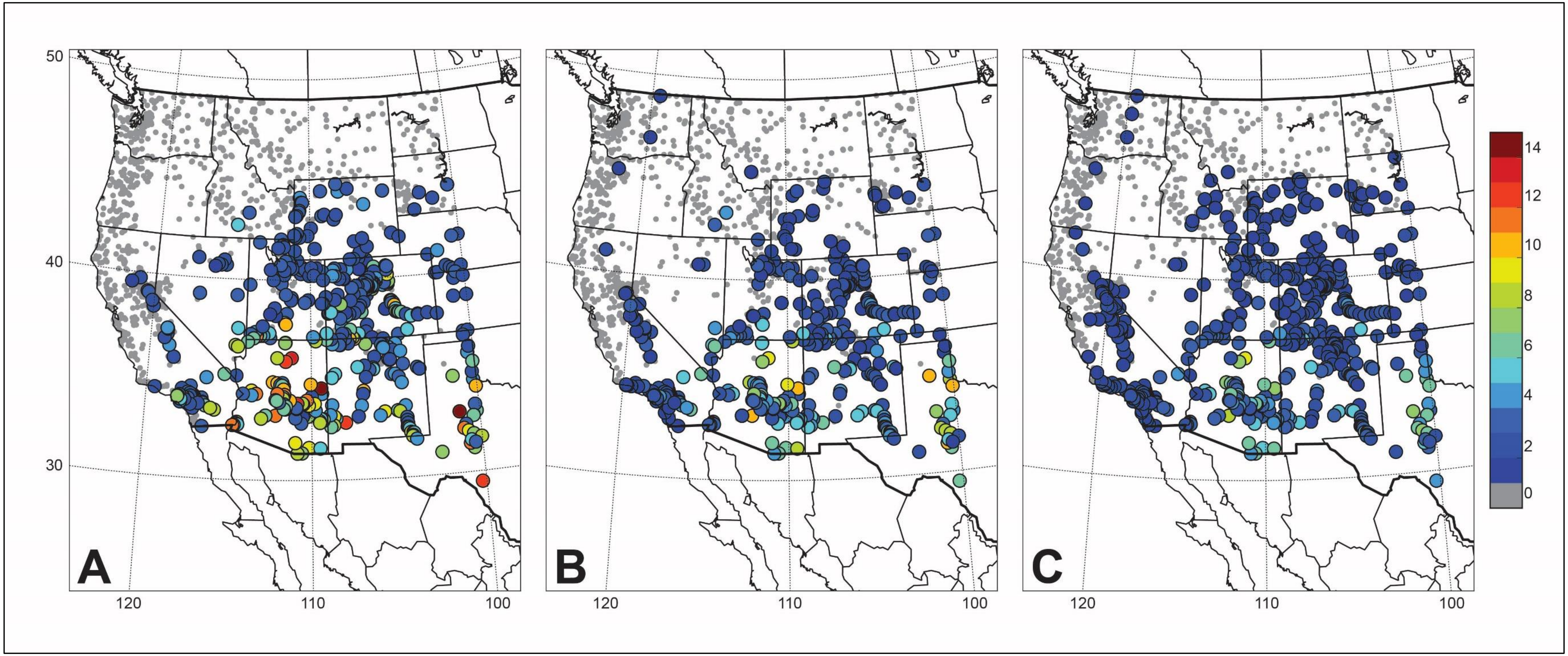




Cumulative precipitation and annual maxima attributed to a TC-event

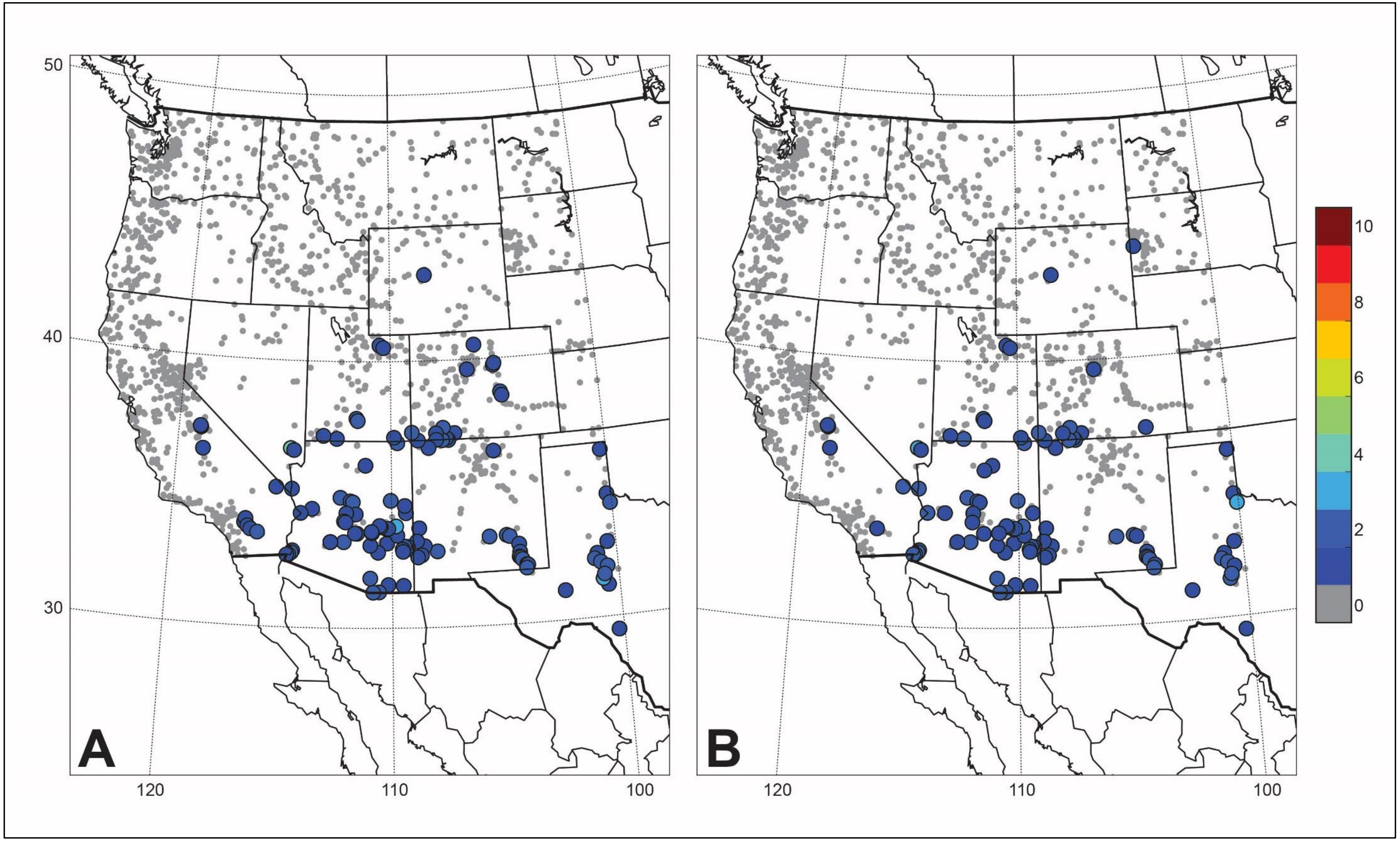


TCs are responsible for a small fraction of annual maximum flows in the western United States



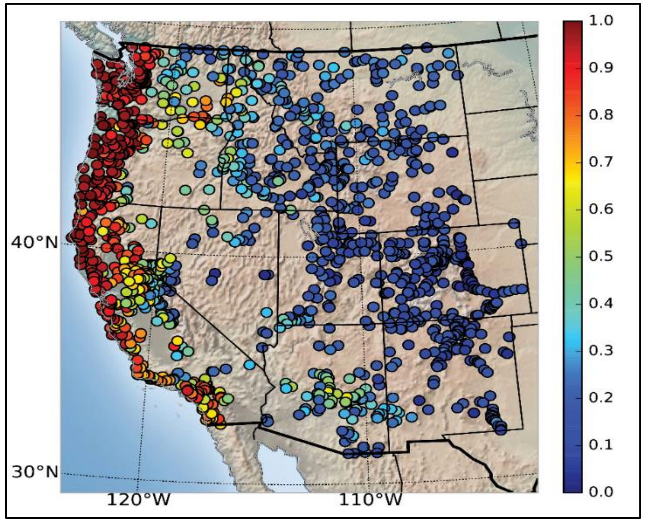
(Barth et al., 2018)

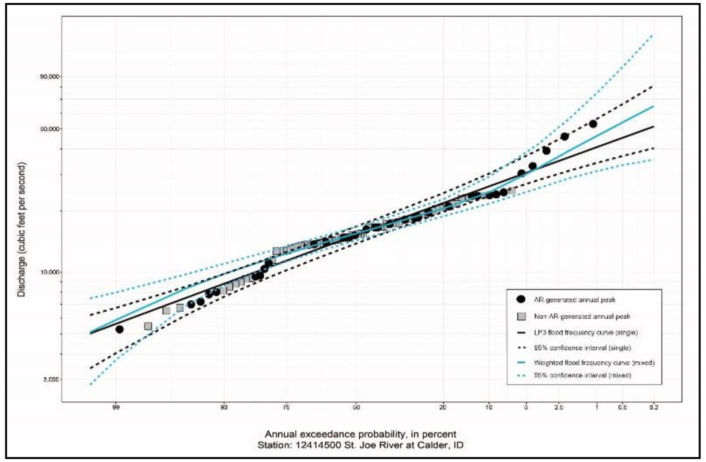
TCs are responsible for a small number of annual maximum flows among the top-10 flows in the western United States



(Barth et al., 2018)

Motivation and objectives



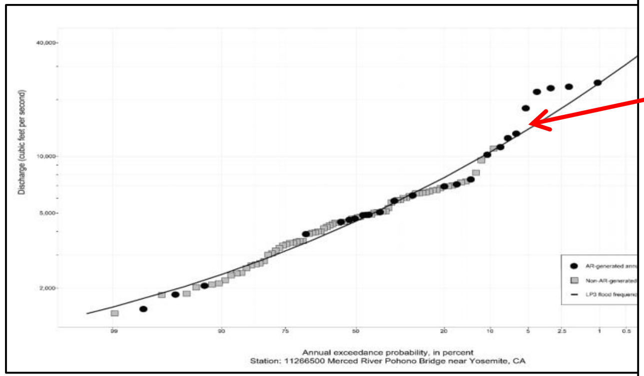


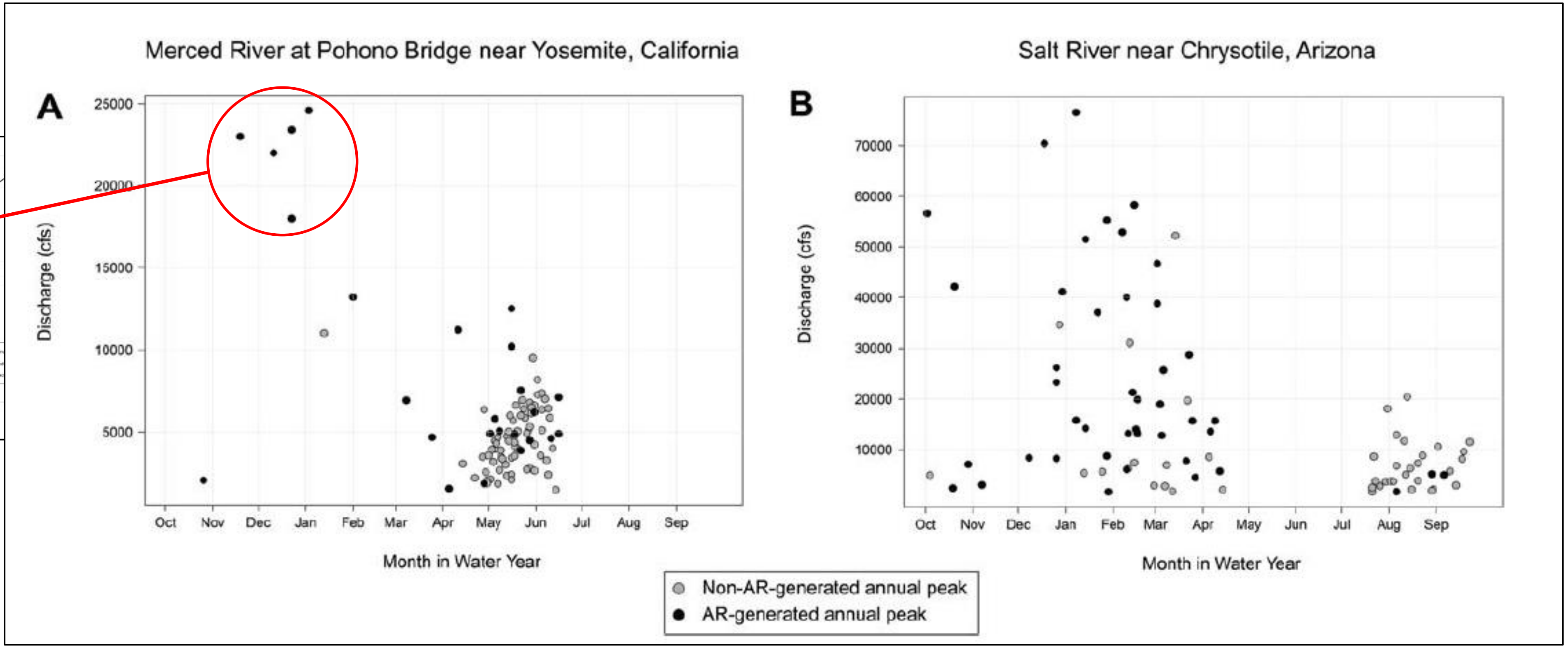
Methodological developments to account for **mixed populations** in flood frequency analysis

Methodological developments to account for mixed populations in flood frequency analysis

Key questions to be addressed:

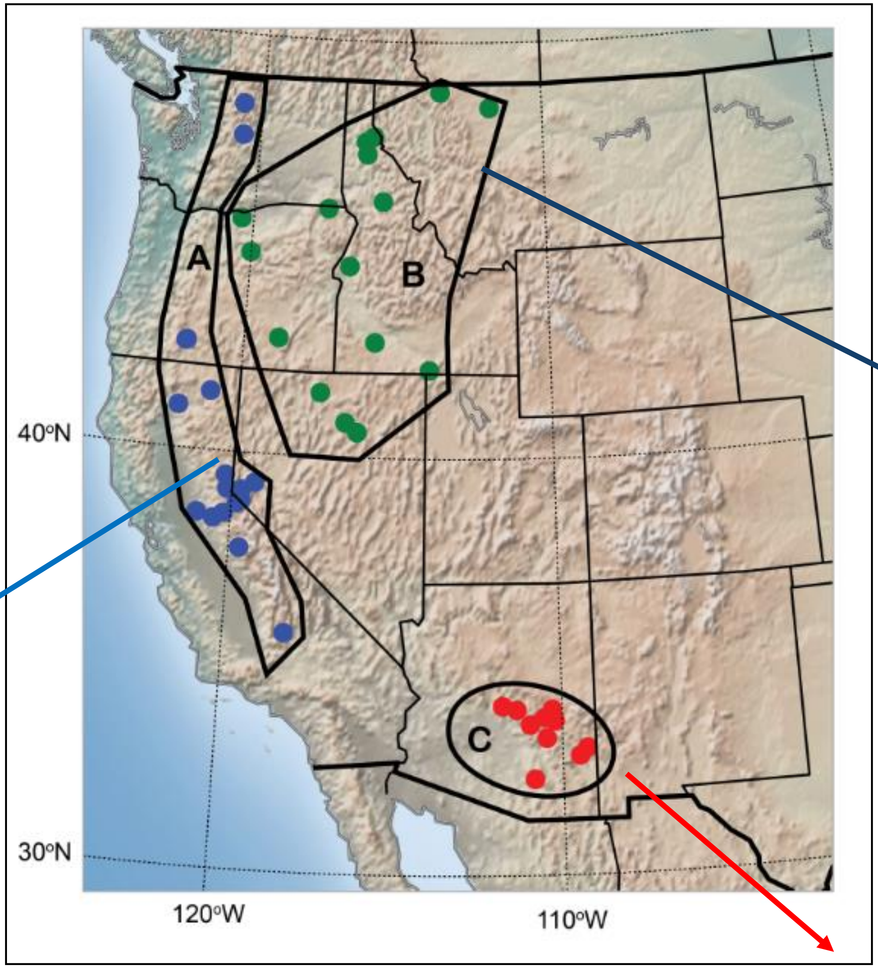
- How do we perform flood frequency analysis by accounting for different flood generating mechanisms?
- What are the improvements in terms of quantile estimates obtained by accounting for mixed populations?





(Barth et.al., 2017)

How do we perform flood frequency analysis by accounting for different flood generating mechanisms?

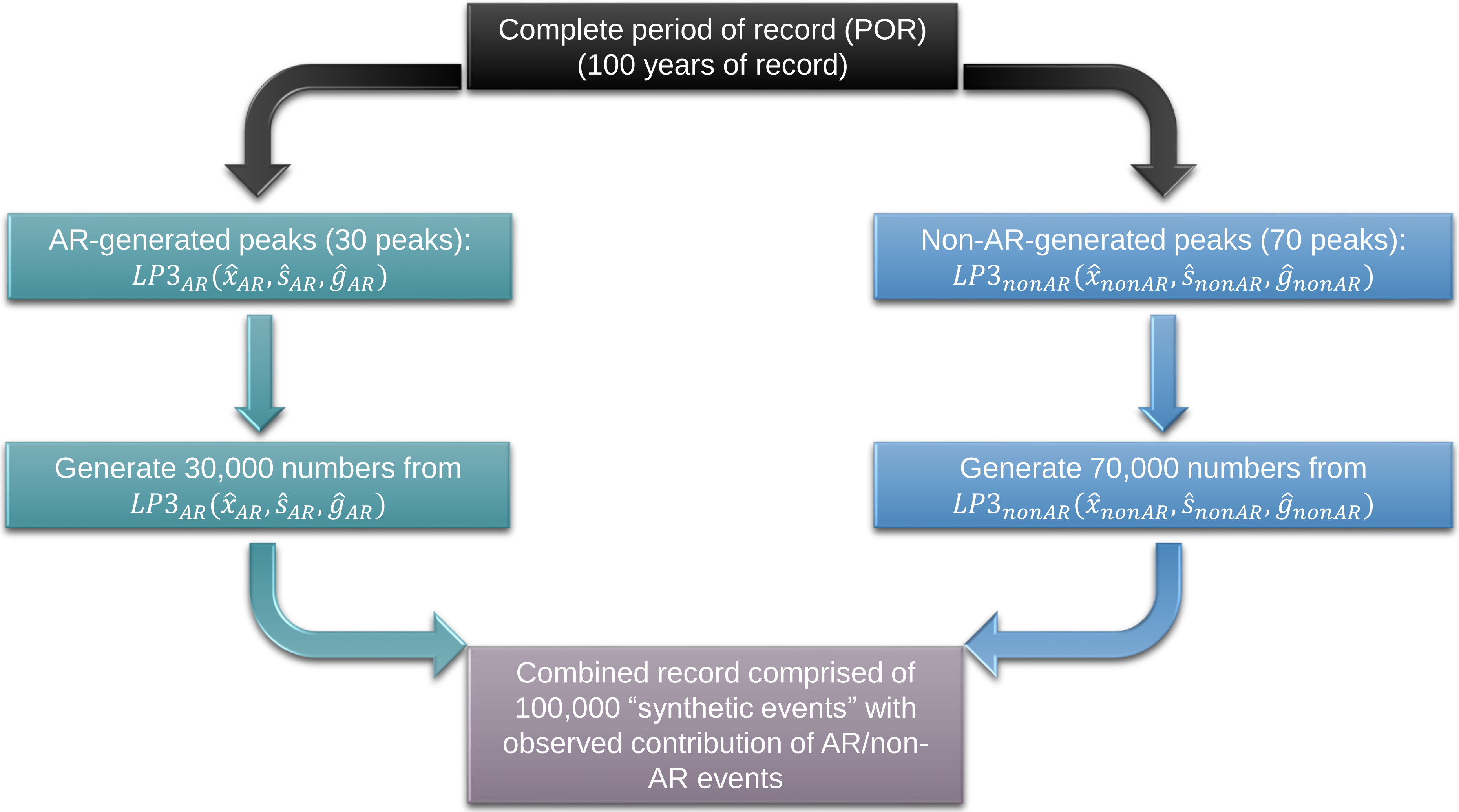


Intermountain West (16 sites)

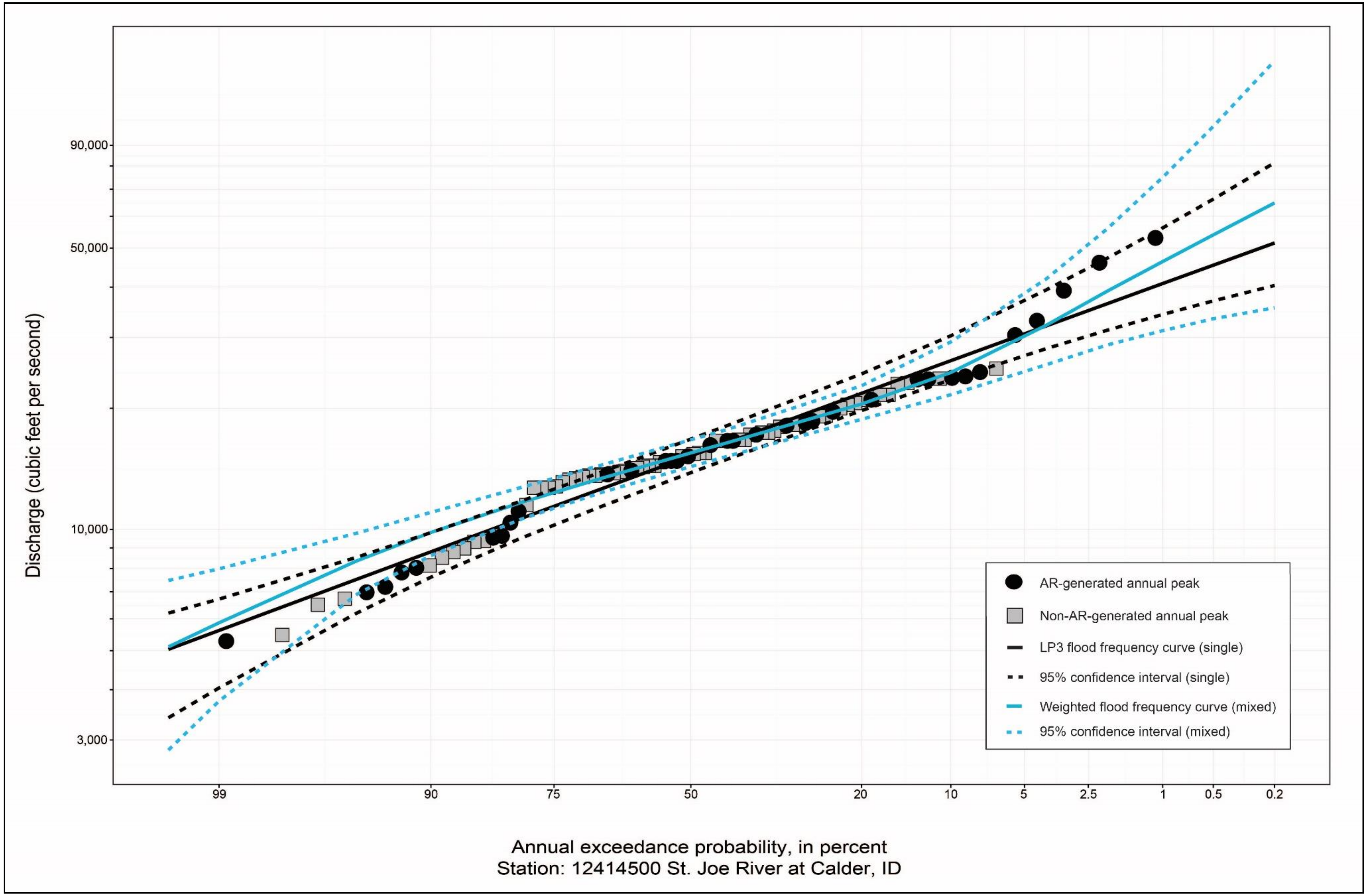
Cascade/Sierra Nevada mountain region (17 sites)

Central Arizona (10 sites)

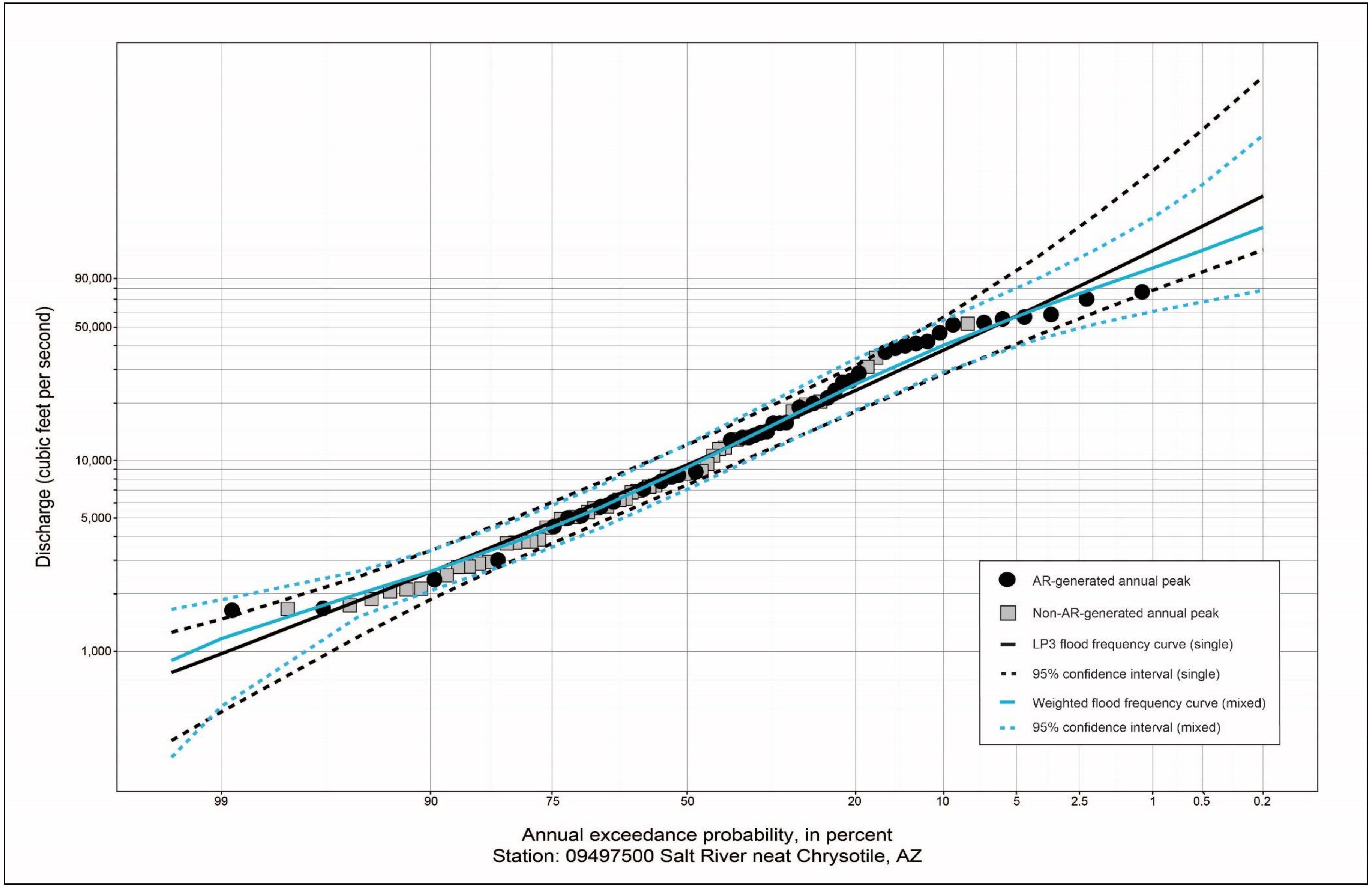
Development of a weighted at-site mixed population flood frequency analysis



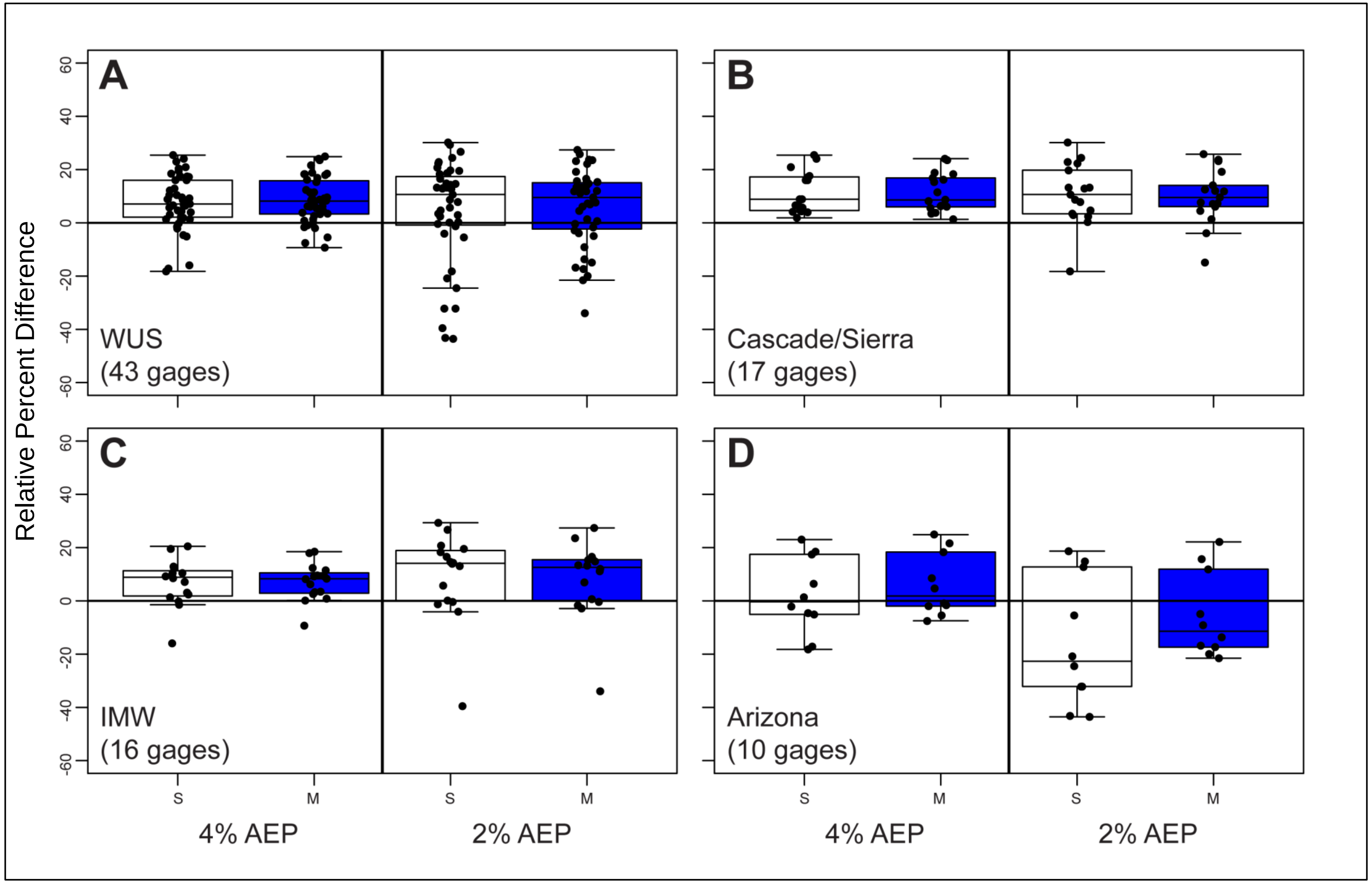
The mixed distribution can better fit the observations



The mixed distribution can better fit the observations

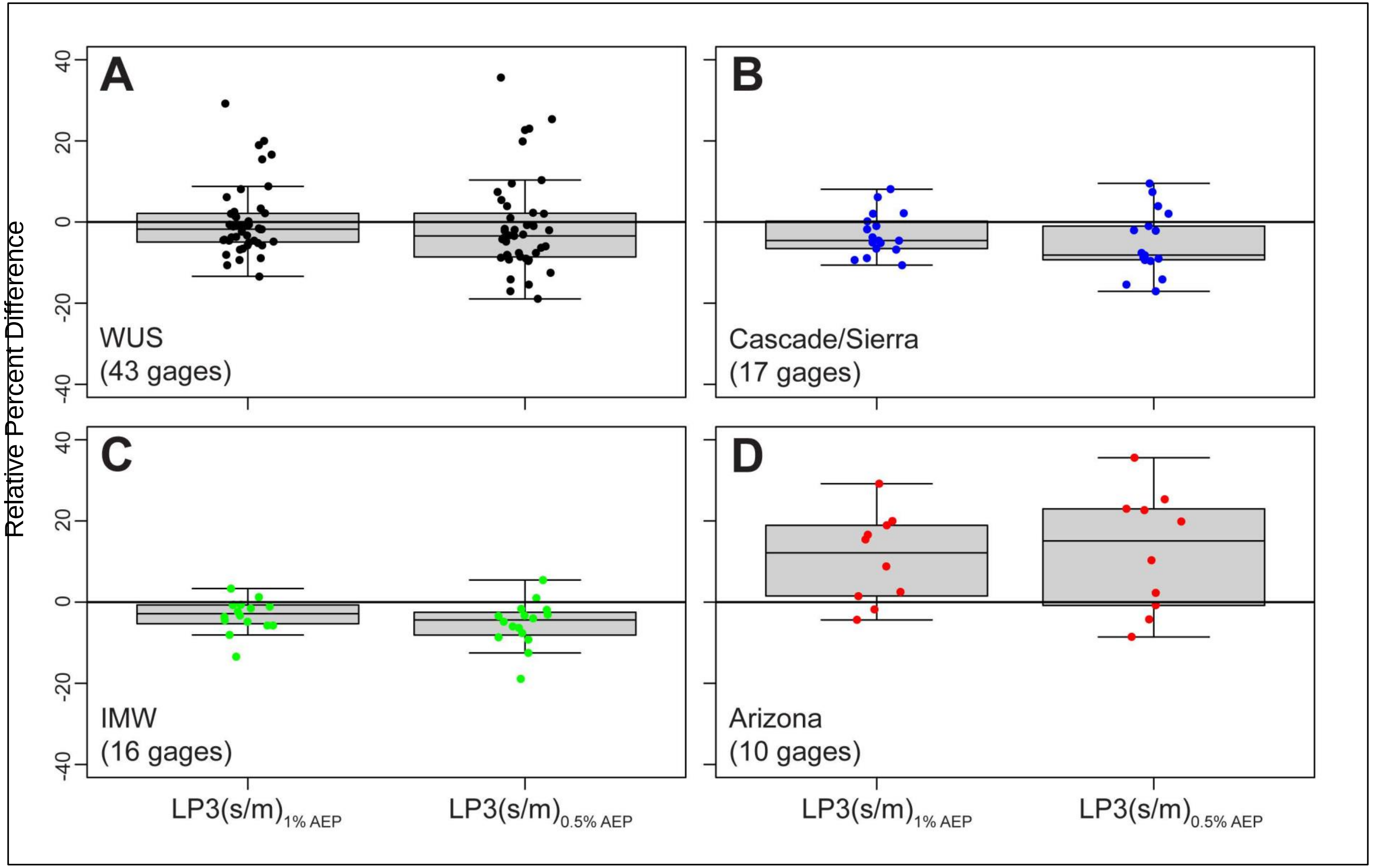


The mixed distribution can better fit the observations



$$\frac{\hat{Q}_{AEP,observed} - \hat{Q}_{AEP,single/mix}}{\hat{Q}_{AEP,observed}}$$

The mixed distribution can better fit the observations



$$\frac{\hat{Q}_{AEP,single} - \hat{Q}_{AEP,mix}}{\hat{Q}_{AEP,single}}$$

Key Points

1. Peak flows throughout the western United States are complicated by flows generated from distinctly different flood generating mechanisms.

2. Atmospheric rivers are responsible for almost all of the annual maxima along large areas of the U.S. West Coast.

3. We have developed a methodology that can capture the effect of different flood generating mechanisms via a mixture of LP3 distributions.

4. Beside more closely reflecting the physical processes at play, the mixed distributions improve the overall fit, especially in the upper tail.

IIHR Hydroscience & Engineering

Questions?
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Additional References

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